AFRL-RH-WP-TR-2009-0024

Novel Presentation Methods for Technical Data

David S. Ebert
Sungye Kim
Insoo Woo
Ross Maciejewski
Purdue University
Department of Electrical & Computer Engineering
701 West Stadium Avenue
West Lafayette IN 47907

Krystal Thomas
Warfighter Readiness Research Division
Logistics Readiness Branch

November 2008

Final Report for June 2007 to November 2008

Approved for public release; distribution is unlimited.

Air Force Research Laboratory
711th Human Performance Wing
Human Effectiveness Directorate
Warfighter Readiness Research Division
Logistics Readiness Branch
Wright-Patterson AFB OH 45433-7604

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//SIGNED//
KRYSTAL M. THOMAS
Work Unit Manager
Logistics Readiness Branch

//SIGNED//
DANIEL R. WALKER, Colonel, USAF
Chief, Warfighter Readiness Research Division
Human Effectiveness Directorate
711th Human Performance Wing
Air Force Research Laboratory

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

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1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
November 2008	Final	June 2007 – November 2008

4. TITLE AND SUBTITLE

Novel Presentation Methods for Technical Data

5a. CONTRACT NUMBER
FA8650-04-D-6546 DO#08

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
62202F

6. AUTHOR(S)

[1]David S. Ebert, [1]Sungye Kim, [1]Insoo Woo, [1]Ross Maciejewski, [2]Krystal Thomas

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER
7184D209

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

[1]Purdue University
Department of Electrical & Computer Engineering
701 West Stadium Avenue
West Lafayette IN 47907

8. PERFORMING ORGANIZATION REPORT

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

[2]Air Force Materiel Command
Air Force Research Laboratory
711th Human Performance Wing
Human Effectiveness Directorate
Warfighter Readiness Research Division
Logistics Readiness Branch
Wright-Patterson AFB OH 45433-7604

10. SPONSOR/MONITOR'S ACRONYM(S)
711 HPW/RHAL

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
AFRL-RH-WP-TR-2009-0024

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
88th ABW/PA cleared on 20 May 2009, 88ABW-2009-2142.

14. ABSTRACT

This project developed effective visualization techniques for 2D technical data diagrams, such as schematic/wiring diagrams for use in maintenance, repair, and training. The techniques have been integrated into the Schematic Diagram Visualization (SDViz) software system that has numerous features to aid in nagivation, diagnosis of faults, and traversal of multiple linked diagrams. These features include highlighting relationships between components and connectors, maintaining context between several related diagrams, animation of electrical/fluid/air flow through the system, marking working status of components/subcomponents, and improving navigation and linking of diagrams through the use of several distortion viewing techniques.

15. SUBJECT TERMS Schematic Diagram Visualization (SDViz), Schematic Diagram Presentations, Job Performance Aids, Maintenance Aids, Small Screen Visualization

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Krystal Thomas
U	U	U	SAR	164	19b. TELEPHONE NUMBER *(include area code)* NA

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. 239.18

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Abstract

This project researched and developed new representation techniques for effective presentation of technical data used for maintenance, repair, and training. The project specifically focused on the navigation and use of schematic and wiring diagrams. The project also performed user evaluations of the effectiveness of these visualization techniques for the tasks of locating specific components and subcomponents (e.g., a pin connection) in schematic and wiring diagrams.

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1. SUMMARY

This project developed effective visualization techniques for 2D technical data diagrams, such as schematic/wiring diagrams for use in maintenance, repair, and training. The techniques have been integrated into the Schematic Diagram Visualization (SDViz) software system that has numerous features to aid in nagivation, diagnosis of faults, and traversal of multiple linked diagrams. These features include highlighting relationships between components and connectors, maintaining context between several related diagrams, animation of electrical/fluid/air flow through the system, marking working status of components/subcomponents, and improving navigation and linking of diagrams through the use of several distortion viewing techniques. Standardized SGML/XML specifications (e.g., MIL-PRF-87269a and Scalable Vector Graphics (SVG) [Ref. 1]) specifications were used to store technical documents enabling the effective querying and display of diagrams over simple bitmap diagrams. To evaluate the value of these techniques, several user studies were performed to evaluate the effectiveness of both highlighting and tracing methods for the tasks of locating a specific component related to an example scenario for training or maintenance. A qualitative user study of an actual aircraft maintenance task was also performed to evaluate the overall benefit of the techniques in troubleshooting a real-world aircraft electrical problem.

2. INTRODUCTION

The “Novel Presentation Methods for Technical Data” research effort was sponsored by the Air Force Research Laboratory’s Logistics Readiness Branch (AFRL/RHAL) under the Technology for Agile Combat Support (TACS) contract (FA 8650-D-6546, Delivery Order #8). The research was accomplished during the period of 1 June 2007 to 1 Nov 2008. The purpose of this effort was to investigate the value of embedding multimedia technologies within procedural instructions for use in the aircraft maintenance domain. Specifically, to determine whether various visualization representations of component parts typically depicted in technical orders as schematics or wiring diagrams are useful in instruction sets involving specific maintenance tasks. This task not only investigated different visualization styles, but also novel interaction and manipulation techniques within the multimedia objects themselves. This objective was achieved by using university laboratory research to quantify significant performance differences among various augmented procedural instruction and navigation types.

3. BACKGROUND

The integration of multimedia techniques within electronic technical data is becoming more feasible as technological costs are driven down. However, the question still remains as to how task effectiveness and novel effective system generation can be achieved using these techniques, as well as the cost effectiveness of integrating these techniques in technical data. Questions also remain as to which maintenance tasks would most benefit from this integration. Visualization

and graphical representation techniques have been incorporated into systems to help the users find and understand relevant information. AFRL/RHAL sponsored initial research work with Purdue University to explore novel rendering techniques to improve user task performance. As part of this research, techniques were developed for effective display of information for maintaining and repairing equipment. The techniques developed allowed the display of digital model data from the desktop to mobile devices using illustrative rendering techniques to create a system capable of displaying many rendering styles that could be selectively applied to more clearly show important information. The project also performed an evaluation of the effectiveness of illustrative rendering methods for locating a specific mechanical part within a model displayed on mobile devices. The main product of the research project was the creation of a device adaptable rendering system for displaying digital model data. Several illustrative rendering styles were developed and a series of preliminary user studies were conducted to refine the techniques. This TACS DO-8 research project extended this earlier research to the domain of complex 2D diagrammatic data. Specifically, the project explored the investigation of rendering techniques for improving the understanding, navigation, and use of complex 2D visual data, such as wiring and schematic diagrams.

4. METHODS, ASSUMPTIONS, AND PROCEDURES

The primary focus of the research in this project was the creation of the SDViz interactive environment for navigating and visualizing schematics and wiring diagrams. In addition, the research also investigated visualization methods for rendering and navigating multiple related technical documents (diagrams), as well as for understanding relationships of components within a single diagram. Highlighting methods based on the relationship between components and connectors to emphasize connected components and paths to both power source and sink were developed. For aiding in contextualizing components in multiple documents, rectangular fish eye viewing, marquee zooming, and magic lens viewing were developed within SDViz, as well as a relational lens that blends the current diagram with a related document, and enables context-preserving movement to the related diagram. Flow animation from a source to a sink was developed to aid understanding the connections in diagrams. A series of user studies was also conducted to evaluate the effectiveness of SDViz and approaches for displaying technical documents. The technical details of the SDViz system, the user study plan, and the results of the user study are described below.

5. SDVIZ SYSTEM

The SDViz system provides users with several effective visualization techniques for technical diagrams, such as schematic and wiring diagrams. The SDViz system consists of a data handling component and four main categories of functionalities for displaying and manipulating the diagrams: highlighting components, distortion viewing components, navigation, and animation (see Fig. 1).

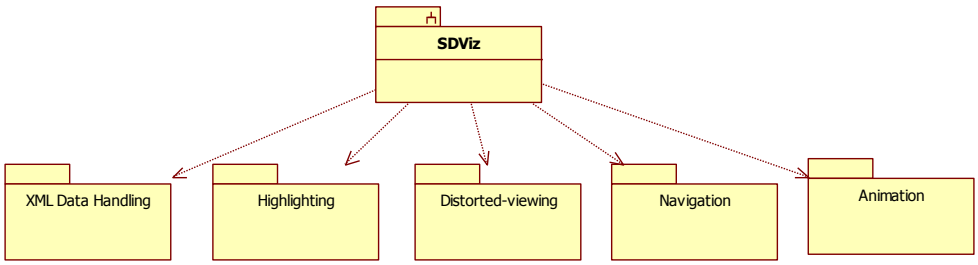


Figure 1: SDViz Functionalities

The development environment for the SDViz used standard tools available on desktop computers running the Windows operating system. Specifically, the development environment used Windows XP Service Pack 2, VC++ 8.0 (Visual Studio 2005), MSXML 2.0, GDI+, and Microsoft .NET Framework 2.0.

5.1 Data Structures

To provide effective component searching in diagrams and context-preserving diagram switching, all diagrams must be searchable with text-based keywords. Therefore, all datasets (i.e., graphics and text files) are stored in the Extensible Markup Language (XML) format, specifically MIL-PRF-87269a and SVG. The SDViz system contains three categories of XML files: one for the schematic/wiring diagrams, one for the connection and link information, and one for all the identification and system information as shown in Table 1. These files could be replaced with an XML database system or be stored in an XML database. Figure 2 shows the relation between the XML files in SDViz shown in Table 1.

Table 1. Category of XML Files in SDViz

Category	Contents
Technical Information	All the technical documents, such as schematic/wiring diagram, Technical Orders (T.O.), and Fault Isolation Trees (F.I.) can be stored in the XML file based on MIL-PRF-87269a. In SDViz, the XML file contains all the links of the schematic and wiring diagrams.
Schematic/Wiring diagrams (Diagram_graphic)	All the diagrams were converted into SVG format that makes it possible to search by text-based components in diagrams. SVG also inherits all of the advantages of using vector data as 2D drawing.
Connection Information (Diagram_comp_rel)	To visualize the connections between components, the components and their link information should be maintained. An additional XML data file was used to keep this information for each diagram.

System Info (systeminfo)	All the aircraft type identifiers, system identifiers, subsystem identifiers, and component identifiers are stored in this file.

(cf. The Document Type Definitions (DTDs) are defined in Appendix B.)

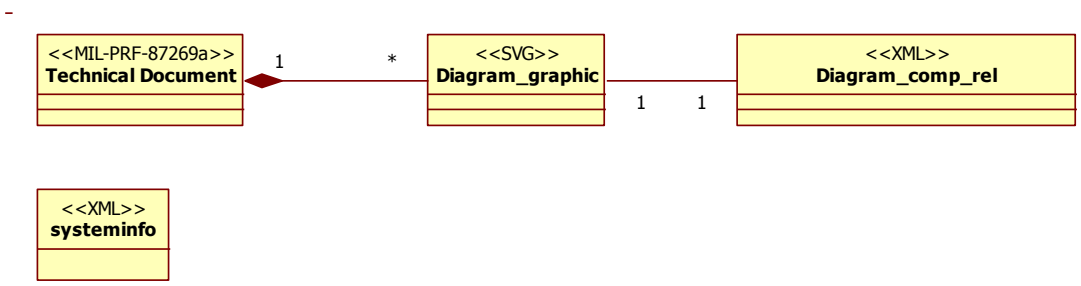


Figure 2: Relation Between XML Files in SDViz

5.2 Basic Framework

The SDViz system provides navigation, search, and rendering of schematic and wiring diagrams. For rendering, the SVG specification includes a number of nodes to support 2D vector drawing, animation, and so on. SDViz supports a subset of these nodes (e.g., clipPath, text, tspan, g, style, path, polygon, polyline, line, and rect) that were used in our diagrams. All the schematic and wiring diagrams are represented with the nodes. Rendering of the diagrams was implemented by using the Extended Graphics Device Interface (GDI+) that provides several operations to draw 2D vector objects and images.

For searching, we take advantage of the capabilities for searching information in XML-tagged Document Instances (DI). All data used in SDViz are stored in XML format. Keyword searching of diagrams is provided by using the XQL query facility. Microsoft XML supports XQL query for the XML DOM tree.

6. VISUALIZATION TECHNIQUES FOR TECHNICAL DATA

As discussed earlier, to support effective visualization of 2D diagrammatic information, SDViz provides several functionalities that can be classified into the following four groups: **highlighting, distortion viewing, navigation, and flow animation.**

6.1 Highlighting

Highlighting enhances the information relevant to the user's task and immediately draws the user's attention by using colors or marks. In SDViz, highlighting is used to emphasize the name of a component that matches the keywords searched in the diagrams, user selected components, and connections between selected components. As mentioned in Section 5.1 Data Structures, each diagram has two XML data files that contain the graphical information of the diagrams and

the connection information in the diagrams. From the connection information, a graph of the connection between components is generated for use in the highlighting.

To highlight a component name, a colored rectangle is displayed around the component name, as shown in Figure 3. The position is obtained by searching the "text" nodes with the component name in the SVG file. The width and height is computed by counting the string length.

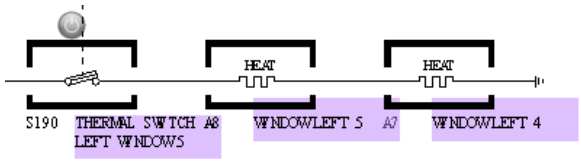


Figure 3: Highlighting of Component Names

To highlight connections in the diagrams, the direction of the connections is represented by interpolating the colors from red (source) to blue (sink). As an example, several highlighted components and connections are shown in Figure 4. The component that contains subcomponents is highlighted together with its subcomponents as shown in Figure 4 (right).

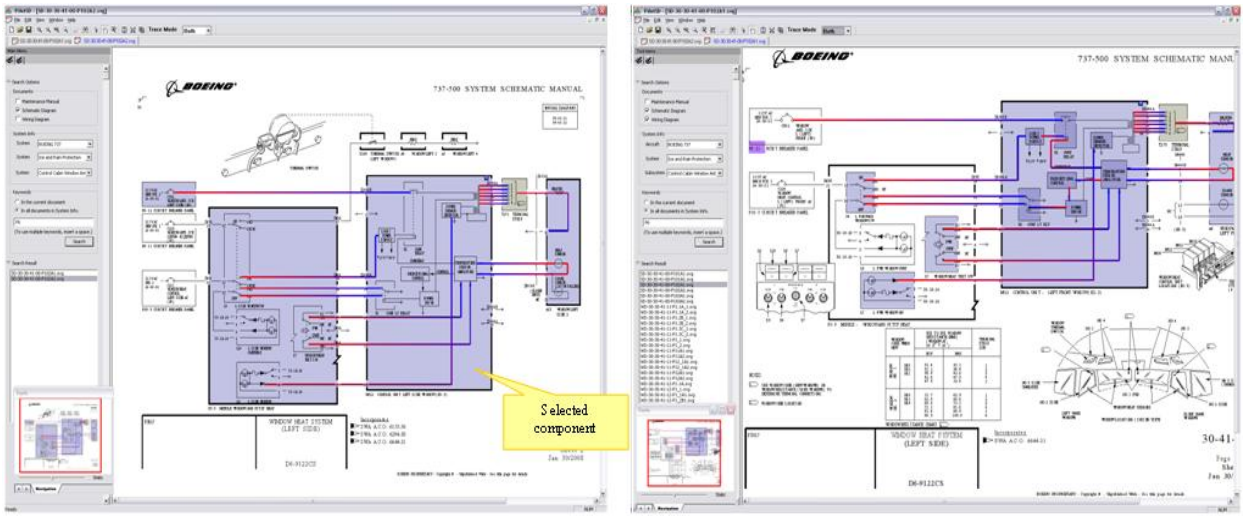


Figure 4: Highlighting of Connections

In many maintenance tasks, visualizing the path from the potential problematic component to the power source is fundamental to help mechanics find out the source of the trouble while tracing the path. As mentioned in Section 5.1 Data Structures, each diagram has two XML data files: the graphical information of the diagram and the connection information in the diagram. From the connection information, a graph of the connections between components is generated. By applying a breadth first search (BFS) algorithm (or depth first search, if preferred) to the graph and the start component, paths from a source to a sink are displayed. Figure 5 shows an example highlighting of the path from a source to a sink.

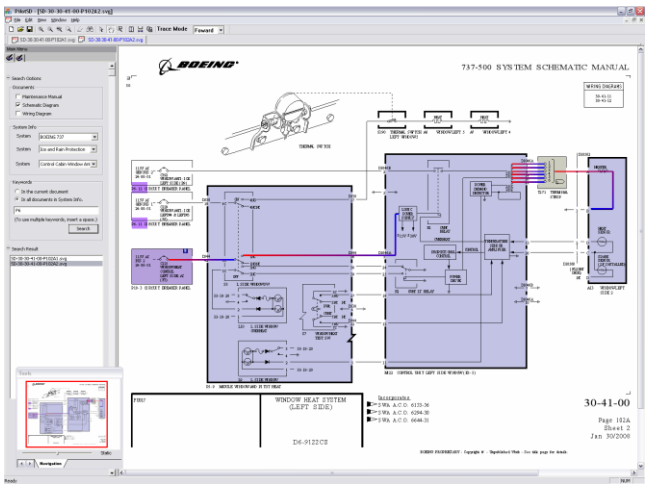


Figure 5: Highlighting Connections Between a Source and a Sink

Another effective form of highlighting is displaying additional information using icons or marks. Special marks such as switch on/off (Fig. 6) as well as working/not-working status (Fig. 7) can be effectively used to make a symbolic note, especially when performing maintenance by referring to multiple-page documents. These special marks are maintained in all the related documents that a user refers to by managing the component's unique identifiers. When a related diagram is opened, all the component identifiers managed in a list are passed to the newly opened document, and the components in the document are marked appropriately.

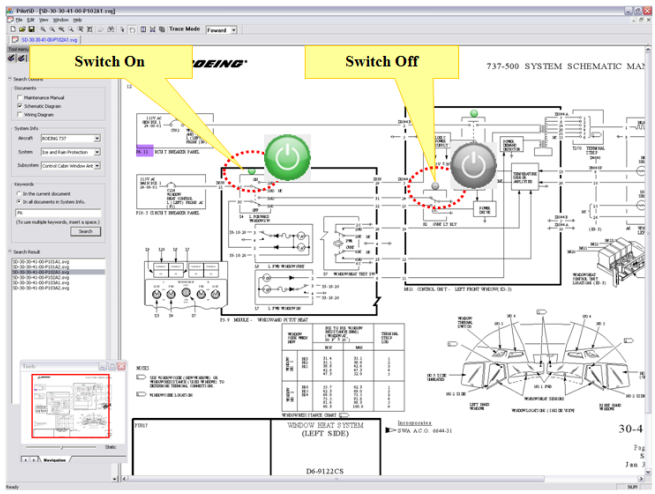


Figure 6: Switch Status

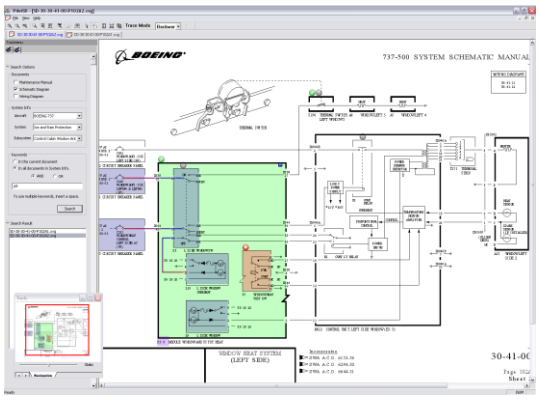


Figure 7: Working Status (Green=Working, Red=Not Working)

6.2 Distortion Viewing

Distortion viewing can be used for effective visualization of relatively large diagrams on small screens as well as for enhancing the user's area of interest (AOI) within the entire context of a diagram. The distortion viewing techniques can be classified based on whether a user can control the size of the distortion area or not. In SDViz, our magic lens uses a fixed-size lens to enhance a specific area, and our relational lens uses a fixed-size lens defined, not by the user, but by the size of each component in the diagram. Both SDViz' marquee zoom and rectangular fisheye size can be set by a user-defined area.

A **magic lens** is similar to a magnifying glass and can be used to visualize and emphasize the details of a portion of a diagram. The diagram displayed under the fixed-size (e.g., 200×200 pixels) lens can be shown in twice the scale of the current diagram. In SDViz, the system magnifies the portion of a diagram under the lens and, furthermore, assigns a see-through capability to the magic lens. An example of a magic lens view is shown in Figure 8. In this image, the schematic diagram is displayed in the initial scale, and the area under the magic lens is magnified.

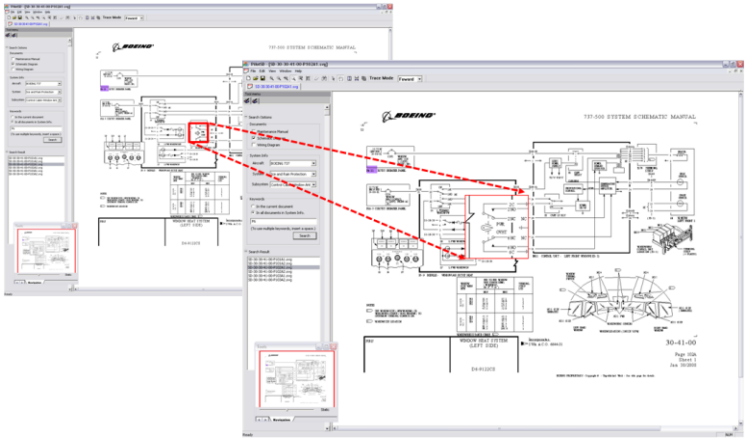


Figure 8: Magic Lens

A **relational lens** is a variation of a magic lens that can be used to see the information in the related diagrams (e.g., schematic diagram and the related wiring diagram and vice versa). Figure 9 shows an example using the relational lens on a schematic diagram to see the wiring details of the user's focused component. The relational lens can be applied to each electrical component in a diagram. When the mode for a relational lens is on (a user toggles this mode on the tool bar), the related wiring information of the focused component in the current schematic diagram is searched and overlapped on the focused component automatically. If there is no related information found, nothing is changed. In Figure 9 (right), the green rectangle shows the area visualized by the relational lens.

The information from the related diagram in the relational lens is visualized in the same scale as the current diagram. From our experience, the different size of components in each diagram can produce awkward, view-overlapped results that may confuse a user. Hence, in SDViz, the relational lens is used with a transitional blending function. *(For details, see 'Transition-by-blending' in 6.3 Navigation.)*

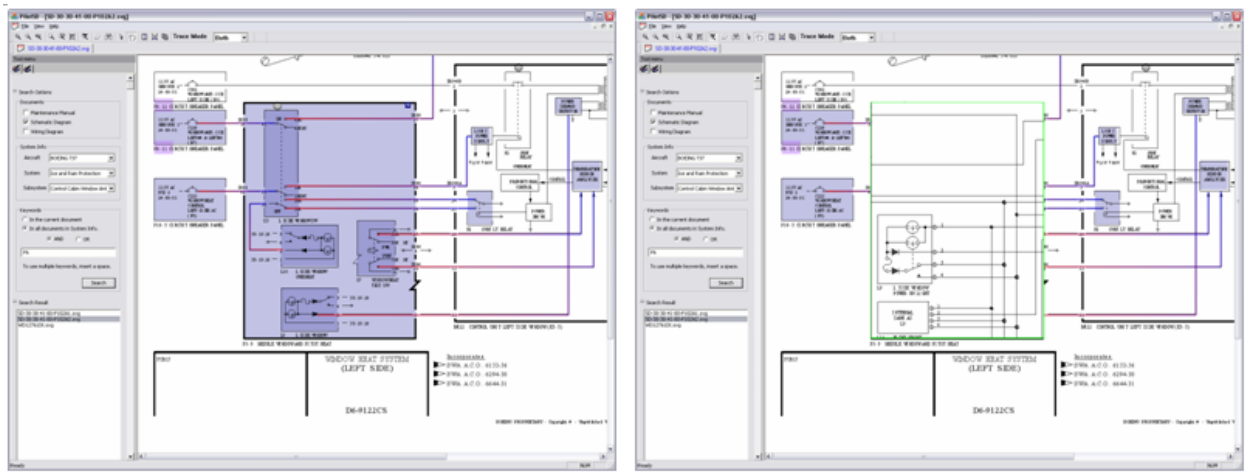


Figure 9: Relational Lens–A Schematic Diagram with a Focused Component (left) and Wiring Details Overlapped on the Component (right)

A **marquee zoom** is a basic zoom function that enlarges a user-defined rectangular area, obscuring adjacent information. The scale factor for the marquee zoom is determined by the ratio of the size of the user-defined area and the screen size. The user-defined area is extended to the entire screen starting from the left top corner and maintains the aspect ratio such that most of the adjacent information, particularly left top side, will be lost. Figure 10 shows an example of the marquee zoom.

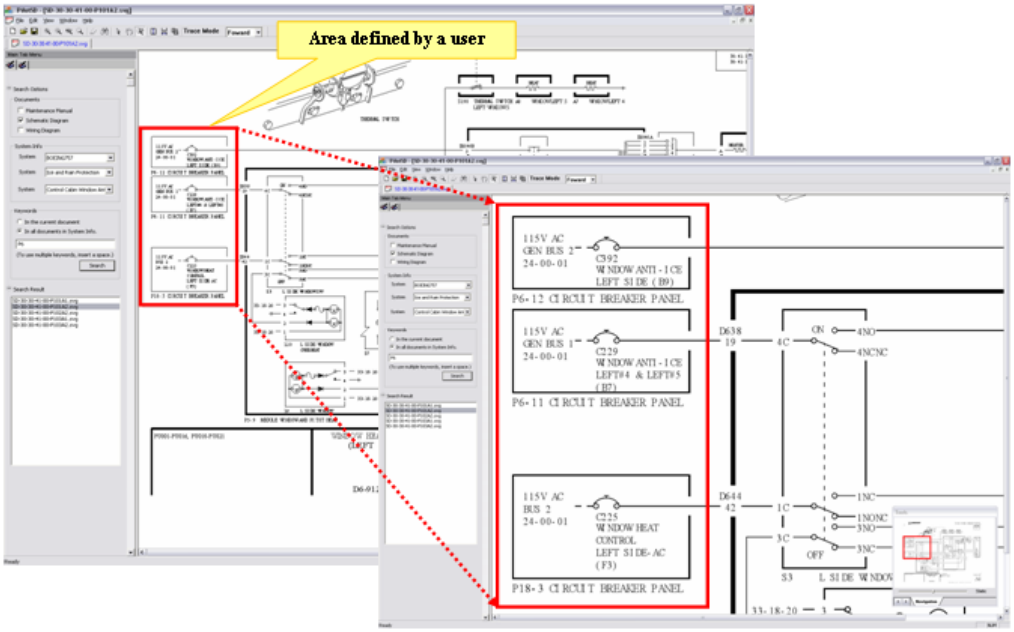


Figure 10: Marquee Zoom

A **rectangular fisheye** [Ref. 2] is a variation of a general circular fisheye view that divides the screen into several small areas and applies different scale factors to each part. Fisheye lenses distort the view to enable seeing more contextual information while preserving the viewing of the focus area (each component in the context is made smaller). In SDViz, the screen is divided into nine areas when a user selects the rectangular fisheye. The center area (area of interest) has 1×1 scaling and is defined by a user's mouse dragging. The other areas in the diagram are computed based on this center area. Figure 11 shows the scale factors used for the rectangular fisheye in our SDViz system.

.5 × .5	1 × .5	.5 × .5
.5 × 1	1 × 1	.5 × 1
.5 × .5	1 × .5	.5 × .5

Figure 11: Split and Scale Factors of a Screen by the Rectangular Fisheye

An example of a rectangular fisheye in SDViz is shown in Figure 12. In this figure, the nine areas are divided by blue dotted lines as a user defines the center area. Each area is visualized with the corresponding scale factor while preserving the scale of the center area as well as providing more adjacent information around the center area in the diagram.

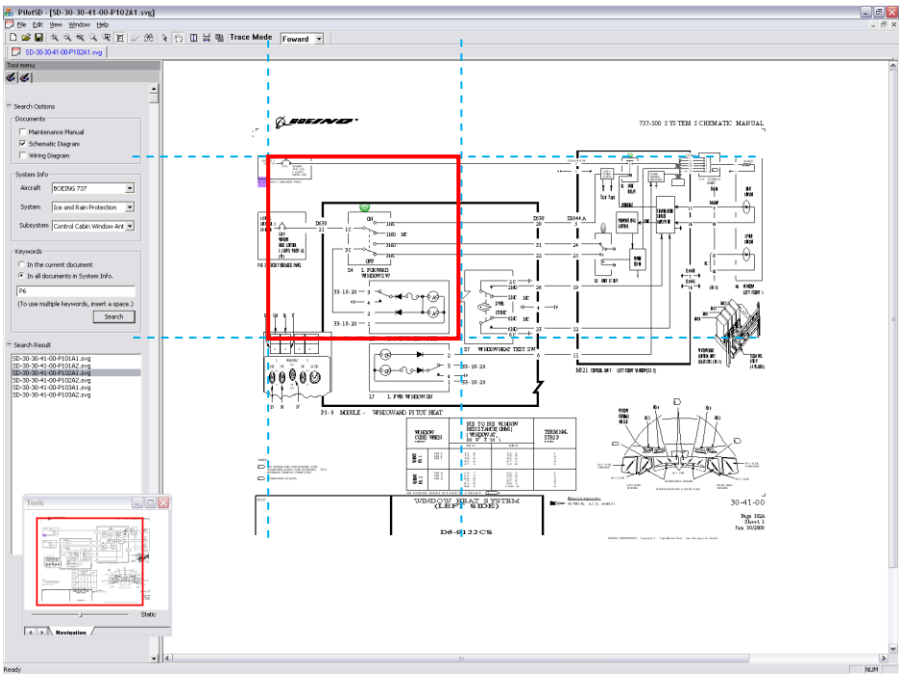


Figure 12: Rectangular Fisheye of a User-defined Area in a Schematic Diagram

Figure 13 shows the difference between using the rectangular fisheye and general zoom-out. In this figure (left), the user's area of interest is shown in the red rectangle maintaining the original scale. In the case of using a general zoom-in, the entire diagram is affected by the down scaling. Both views in Figure 13 show similar adjacent information around the area of interest, but the rectangular fisheye provides better visualization for the user's area of interest.

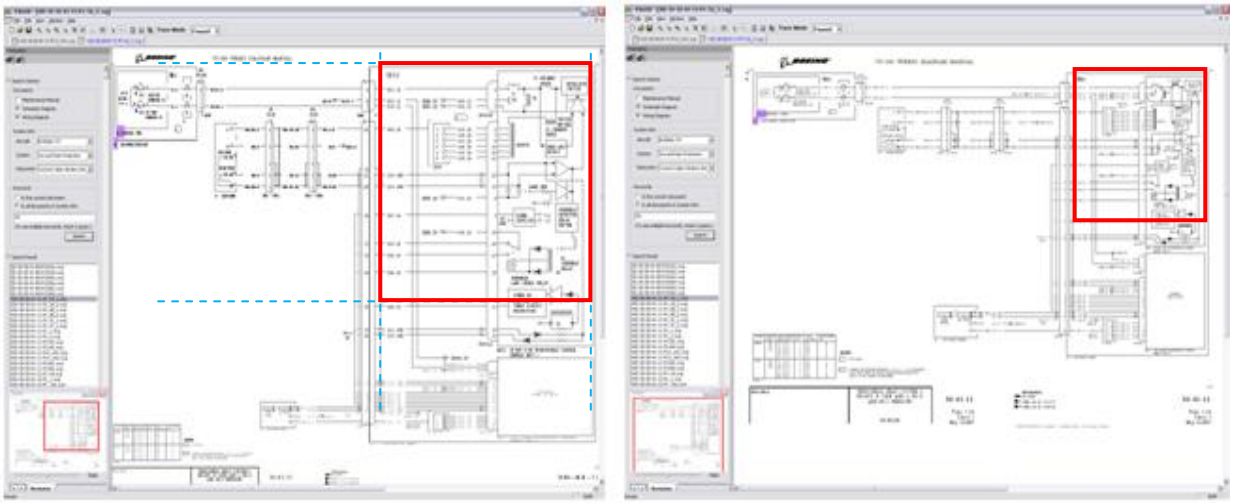


Figure 13: Difference Between the Rectangular Fisheye (left) and Zoom-out (right)

6.3 Navigation

Navigation is one of the most fundamental functionalities in order to utilize technical data in performing maintenance, troubleshooting, repair, and training tasks. In SDViz, navigation is categorized into two types: **single-diagram navigation** and **inter-diagram navigation**. The navigation within a single diagram includes searching keywords in the current diagram, jumping to the connected neighbor component, finding a specific component such as a power source, tracing forward or backward from a component, and transforming the view by the user's mouse dragging using a hand tool.

The inter-diagram navigation involves searching keywords within the entire system and moving to the related diagram. Moreover, the inter-diagram navigation raises an important issue for technical data such as schematic/wiring diagrams: maintaining the contextual information between the related diagrams. Additionally, SDViz also provides a tree view of all the diagrams within the entire system.

The overview window displays an additional view of the entire diagram, allowing the user to easily keep an overall structure of the diagram, as shown in Figure 14. A rectangle inside the overview window contains the same part of the diagram that the current view shows. The user may drag the rectangle to change the current view.

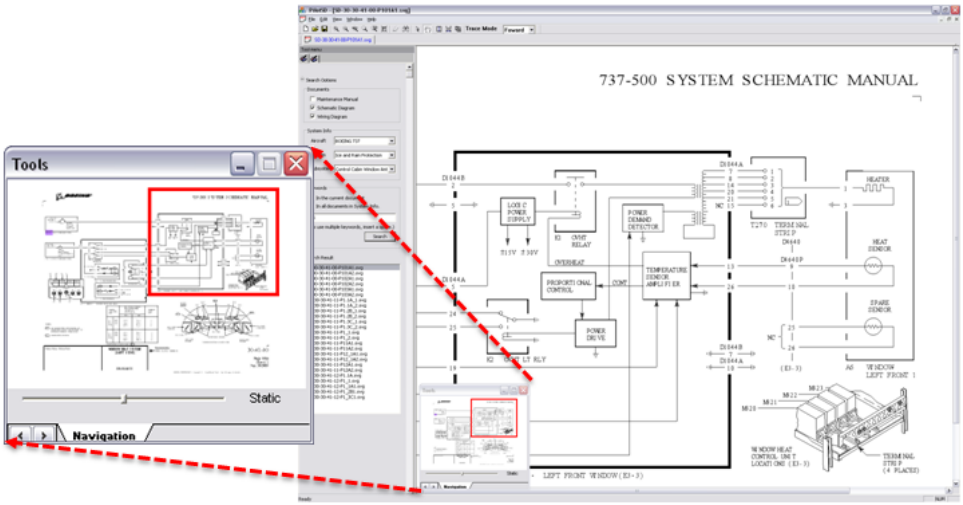


Figure 14: Overview Window

Keyword search in SDViz can be used to find the initial diagrams for the task at hand. The SDViz provides two options for keyword searching: search keywords in the current diagram or search keywords in the entire system information. For example, a user could select 'Boeing 737,' 'Ice and Rain Protection,' and 'Control cabin Window Anti-icing' within the 'Aircraft,' 'System,' and 'Subsystem' information. From all diagrams corresponding to this system information, SDViz searches keywords resulting in the list of diagrams that include the keywords.

A user can click one of the diagrams to open. Figure 15 shows an example of the two types of keyword searches, highlighting the keywords in different colors.

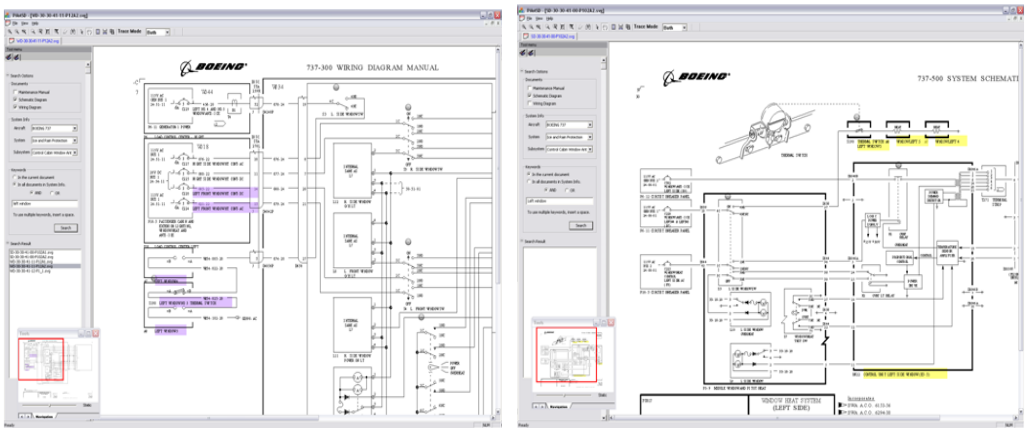


Figure 15: Keyword Search in the Entire System (left) and in the Current Diagram (right)

Single-Diagram Navigation

For navigating within a given document, SDViz is designed for the common tasks used in maintenance and repair using schematic diagrams: the ability to move to the neighbor of a component and find a power source. To help maintain context within the document, an overview is also provided.

Since most components are connected to adjacent components by link connections, SDViz provides the ability to move to another connected component by selecting the name of the component in the context menu, 'Trace,' placing the target component in the center of the screen. Figure 16 shows an example of using the context menu. When viewing large diagrams, this can be useful to navigate within a diagram without tracing links explicitly.

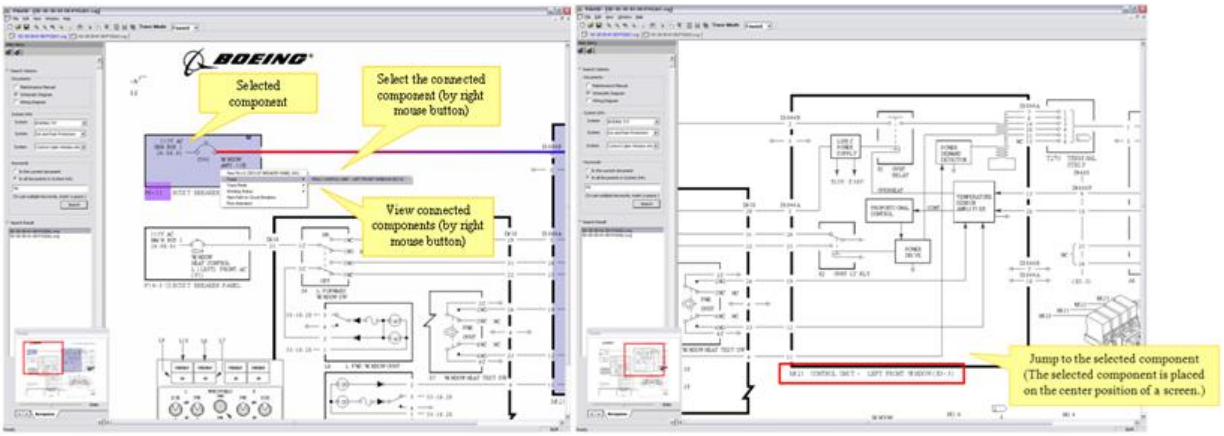


Figure 16: Moving to the Connected Neighbor Component

Additionally, when a component has been selected as the focus, links and components are highlighted on the backward path from the component to the power source to quickly identify all components and subsystems that may affect this component receiving power. Figure 17 shows an example of finding a power source from a component, showing the power source at the leftmost end on the highlighted link.

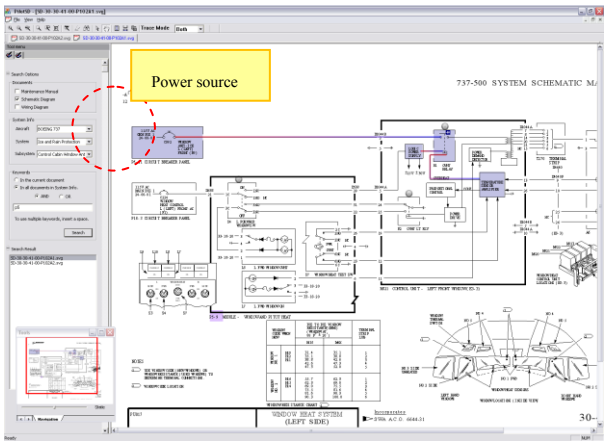


Figure 17: Finding a Power Source

Inter-diagram Navigation

In complex electrical and mechanical systems, most diagrams are related to one or more additional diagrams. For instance, each schematic diagram has a related wiring diagram. SDViz provides the ability to move to the related diagrams without searching, using a ‘Link’ context menu. Figure 18 shows an example of movement to the related wiring diagram from a schematic diagram.

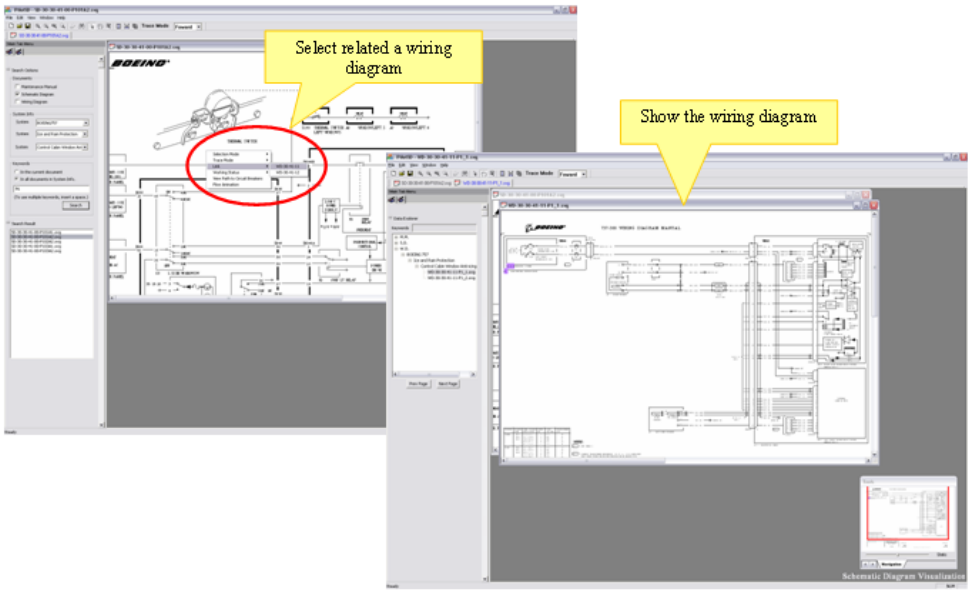


Figure 18: Movement to the Related Diagram Using 'Link' Menu

Another feature in SDViz for inter-diagram navigation uses blending of the related information.

Transition-by-blending is a method to view the related diagram within the current diagram view without explicitly opening the related diagram. If the relational lens is on, transition-by-blending preserves the spatial context of the focused component between the two diagrams. Figure 19 shows an example of this procedure using transitional blending from a schematic diagram with a focused component to a wiring diagram. Figure 19 (a) shows the same status as Figure 9 (right). A user can adjust the extent of blending by a mouse wheel button, as in (a) to (d). In Figure 19, the size of the focused component in the schematic diagram is smaller than that of the component in the related wiring diagram. Therefore, the green rectangle is increased when moving to the wiring diagram showing the change of the size. The position of the left top corner of the focused component is preserved in order to provide the user with a consistent spatial context.

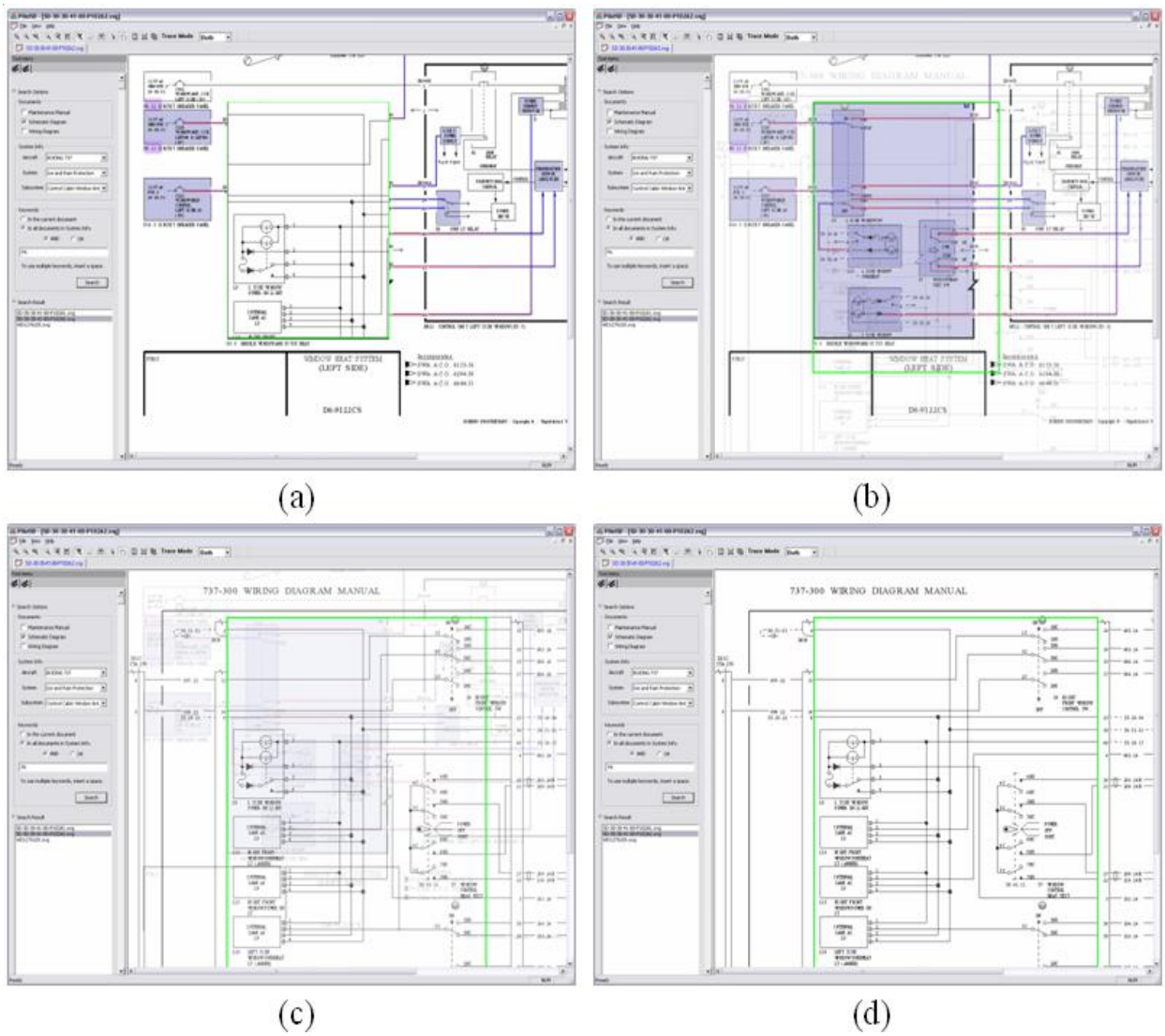


Figure 19: Transition-by-Blending from a Schematic to a Wiring Diagram

For inter-diagram navigation, maintaining the contextual information is essential, because it enables users to keep their focus while switching diagrams. In SDViz, the maintained contextual information includes the changes generated by user interactions such as highlighting, the status of switches, the working status of components, and movements made by mouse dragging. To maintain such information, all the components are uniquely identified so that changes made by a user are applied in all the related diagrams. Therefore, when a user opens the related diagram, it is displayed on a screen with the same contextual information. Figure 20 shows an example of maintaining the contextual information between related diagrams.

Often, schematic diagrams are simpler than wiring diagrams; therefore, the parent component including any selected components may be solely displayed, or the child component within the

selected component may only be displayed. In such cases, the hierarchical information is used to apply the user's change to the related diagrams.

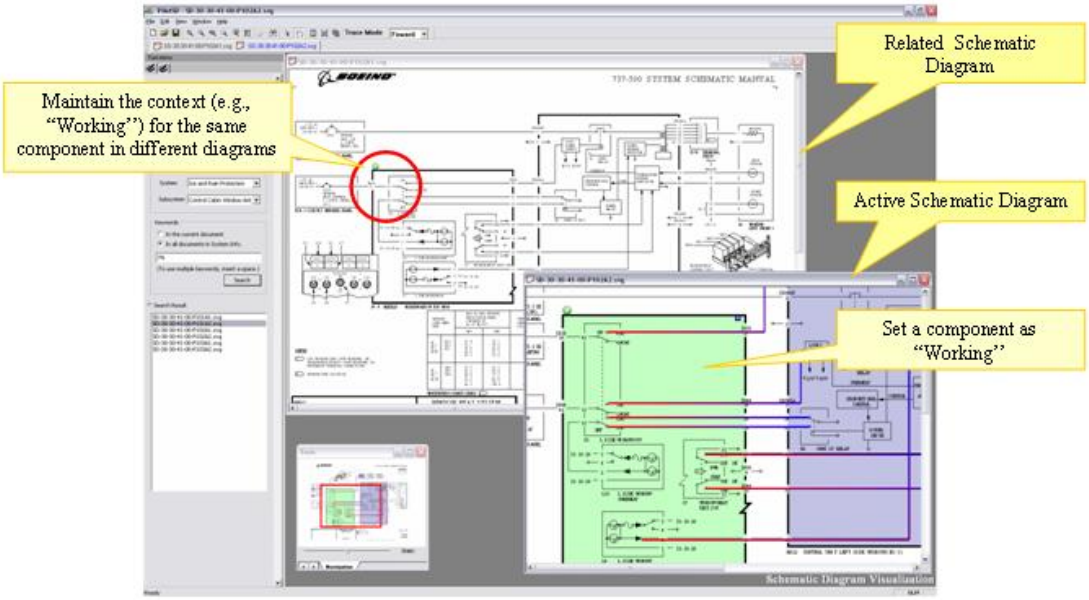


Figure 20: Contextual Information Maintained Between Related Diagrams

6.4 Flow Animation

From our task analysis and discussions with maintenance and repair personnel, noting the flow of electricity, air, or fluid is often a step that is taken during troubleshooting operations. One effective approach to display flow is to use animation. In SDViz, we developed a flow animation capability to show system functions and flow in both schematic and wiring diagrams. With the connection information and graph search algorithm, we can find all connections, the connectors, and all components that are used in the animation. Each connector and component has a different start time for the animation. While recursively traversing the graph, a certain time interval (e.g., 2 seconds) is added to calculate the start time of the next connectors along the path.

For example, in Figure 21, each connector computes the total length, $(l_1+l_2+l_3)$, of its line segments. The length of the first line segment of a connector is subtracted from the total length, (total length – l_1). If the result of the subtraction is positive, the line segment is drawn. This process is performed recursively until the total length equals less than zero.

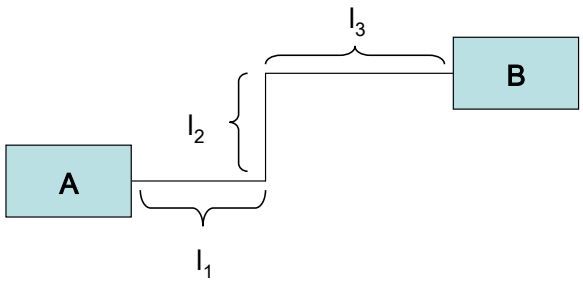


Figure 21: Example of Connections for Flow Animation

The flow animation can be controlled by the status of switches within the document. The flow animation is displayed according to the status of the switches along the path. Figure 22 shows an example of flow animation based on the status of the schematic switches.

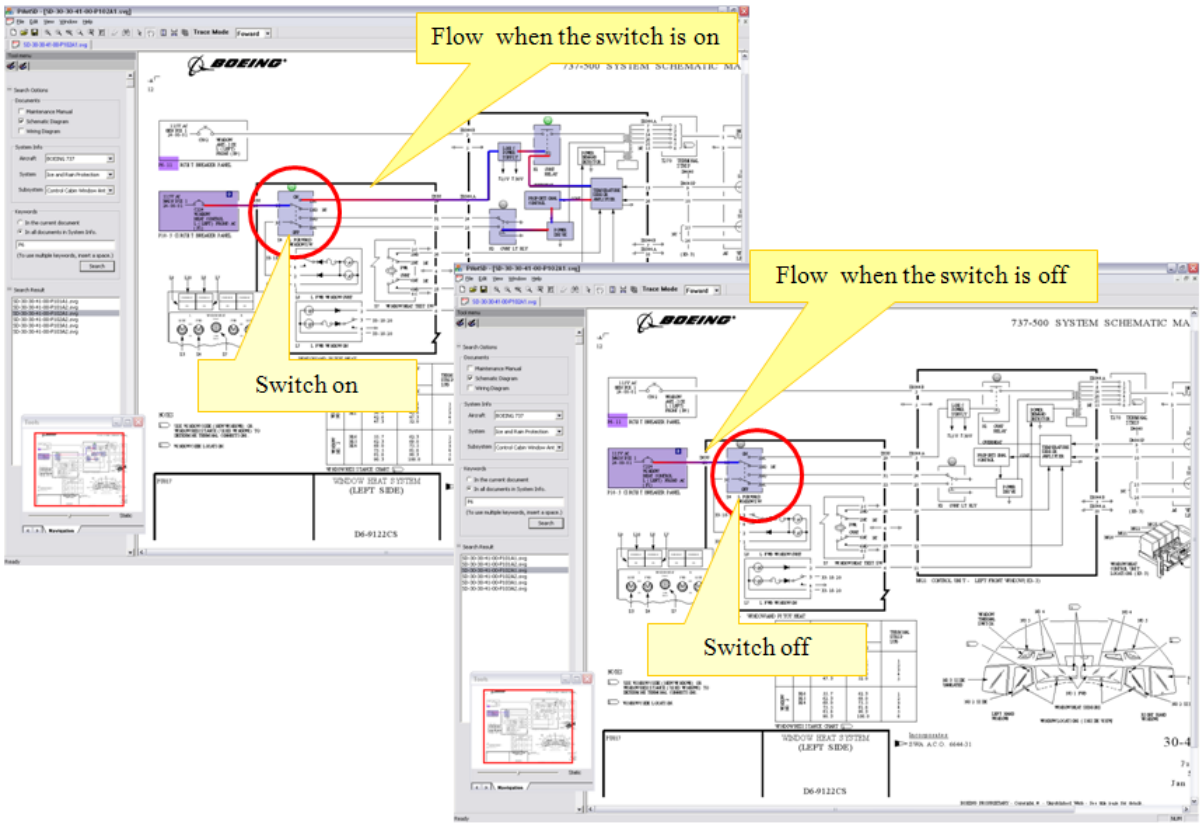


Figure 22: Flow Animation According to the Switch Status

7. USER EVALUATION STUDY

There have been few previous attempts to analyze the impact and effectiveness of presentation techniques for technical data. Recently, Heiser et al. [Ref. 3, 4] identified the cognitive design principles for automatically generated assembly instructions through user experiments. The evaluation of visual representations can be performed at the component, system, or work

environment level [Ref. 5]. At the component level, a common practice is to use controlled experiments in which selected visualization components are systematically varied and other input components are kept consistent. Effectiveness, efficiency, scalability, and user satisfaction are the standard metrics for usability evaluation. For our empirical user study, we designed experiments that evaluated the effectiveness of our proposed novel presentation methods for technical data using our SDViz. The *effectiveness* is defined as the measurement of a technique's ability to enhance the user's understanding of technical data and task completion time by maintaining/enhancing contextual information between related schematic/wiring diagrams. Quantitative measurements, including both user response time and the number of operations (e.g., mouse clicks during task completion), were collected to evaluate the effectiveness that the proposed presentation techniques for technical data had on users' performance. Additionally, subjects completed a questionnaire for qualitative feedback.

This user study was comprised of structured interviews and three small task simulations in order to evaluate the effectiveness of the following visualization methods:

- **Task 1**: Maintaining contextual information between related schematic/wiring diagrams by highlighting techniques.
- **Task 2**: Maintaining context using distortion viewing vs. tabbed browsing.
- **Task 3**: Showing current flow direction vs. static highlighting links.

Finding a component (e.g., electrical node, wire, pin number, power source, and switch) in a schematic/wiring diagram as well as identifying the relationship of components between related diagrams is fundamental to mechanical training and maintenance tasks. For evaluating the effectiveness of presentation techniques for technical data in SDViz, we asked subjects to find a specific component in a schematic/wiring diagram. Subjects performed repeated trials for each task. A preliminary user study was conducted to ensure that the trials were of equal complexity.

Prior to the actual experiment, subjects were given a training session to familiarize themselves with the system's functionality. During the training, subjects asked questions and received guidance in the use of the system. Once the training was completed, subjects were given a pre-test to determine their ability to use the SDViz system. Subjects who did not possess rudimentary efficiency in using schematics did not participate in the full experiment. Once a subject passed the pre-test, they performed the actual experiments in order of the repeated trials and tasks randomized using a magic square method [Ref. 6].

In our user evaluation study, there were 49 subjects (42 males and 7 females). Subjects were familiar with wiring diagrams from a previous circuit course but had no experience using schematic or wiring diagrams of aircraft. Subjects who did not pass the pre-test had time for re-training and were given the pre-test again.

Data collected from each task was subjected to an analysis of variance (ANOVA) testing to determine if the mean time and accuracy of task completion were significantly different between the groups.

7.1 Task 1: Value of Highlighting

7.1.1 Goal and Design

The goal of this task is to evaluate how our visualization methods for technical data help users find desired information. The task involves several repeated subtask trials that evaluate the effects of our highlighting techniques in wire tracing and in maintaining context when moving from a schematic diagram to the corresponding wiring diagram.

7.1.2 Scenarios

- **Task 1A**

Subjects begin the test with a circuit component highlighted and are asked to locate the 115V AC power source. At this point, subjects in Group A see the path to power sources connected to the component automatically, while subjects in Group B do not. When the subjects find the power source, they double click the circuit component indicating that the subtask is complete. Timing and mouse clicks for this subtask were recorded and used for analysis.

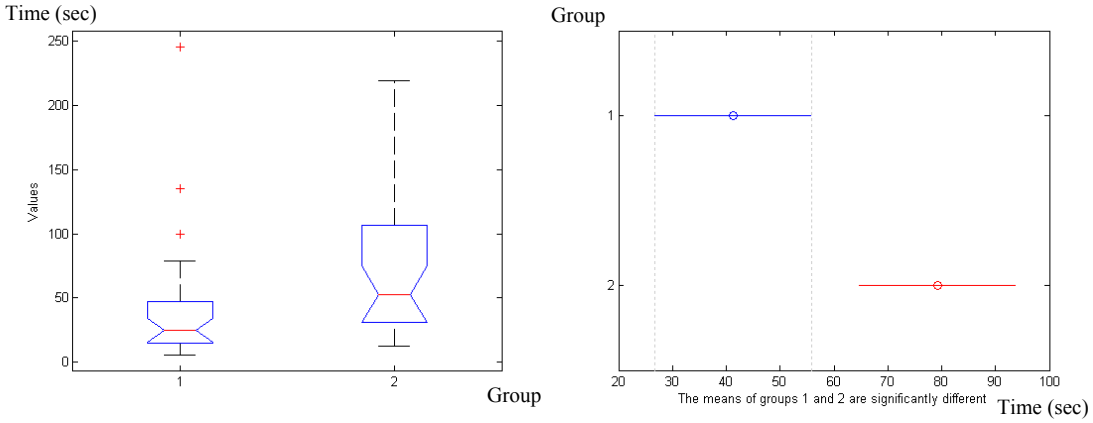
- **Task 1B**

Subjects begin the test with a circuit component highlighted in the schematic diagram and are asked to open the related wiring diagram and find a specified pin connection in the related wiring diagram. At this point, subjects in Group A see the component highlighted in the related wiring diagram, whereas subjects in Group B need to find the component in the wiring diagram again because no contextual information, such as highlighting and spatial information (e.g., a location on the screen), is maintained.

7.1.3 Analysis

The ANOVA results (Fig. 23 and Fig. 24) for Task 1A showed that subjects using our highlighting techniques performed significantly faster than subjects who did not. The mean time for subjects using our highlighting techniques was 28.6681 seconds and the mean time for subjects who had no highlighting options available took 64.0130 seconds. The times were significantly different with *p-value* = 0.0118 for all participants and *p-value* = 0.0066 for participants who had less than two wrong answers. See Tables 2 and 3 for more details.

- **Task 1A - (All participants)**



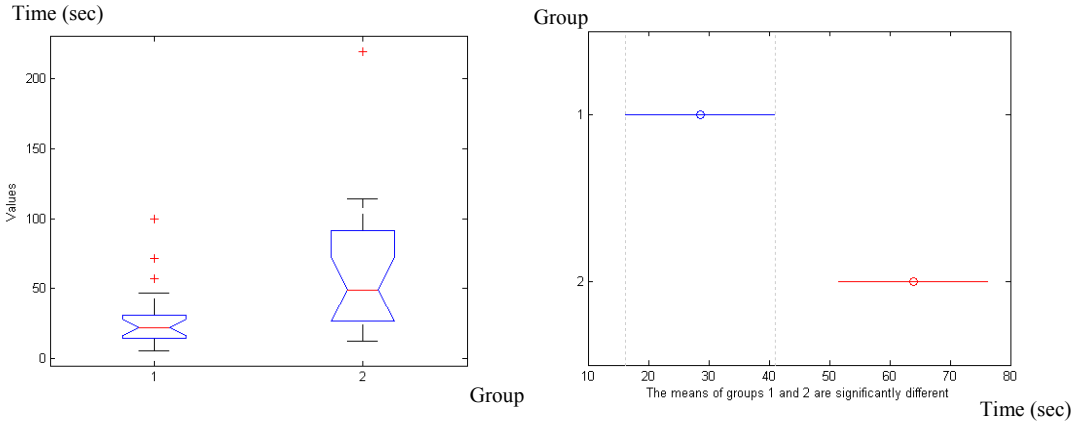
Group 1: highlighting, Group 2: nothing

Figure 23: ANOVA Graph for All Participants in Task 1A

Table 2. ANOVA Table for All Participants in Task 1A

Source	SS	df	MS	F	Prob>F
Groups	20378.1	1	20378.1	6.79	0.0118
Error	165029	55	3000.5	-	-
Total	185407.1	56	-	-	-

- **Task 1A - (Participants who had less than two wrong answers)**



Group 1: highlighting, Group 2: nothing

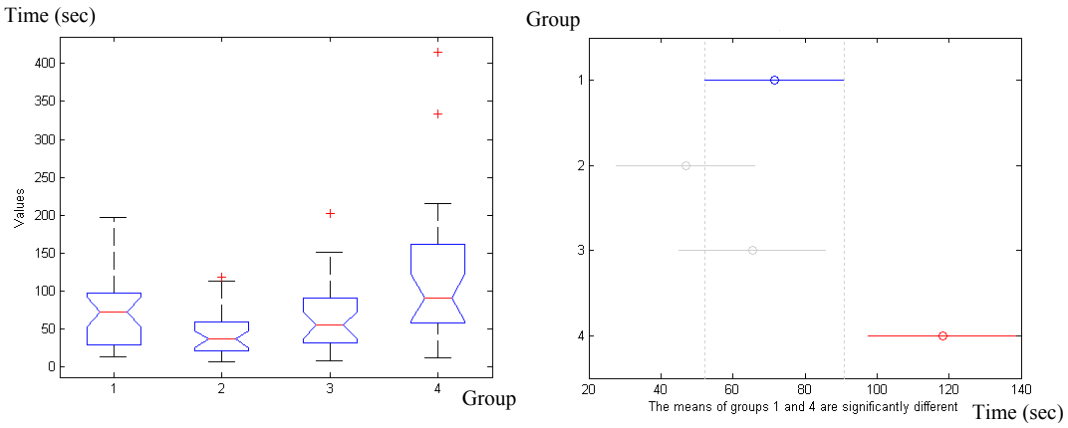
Figure 24: ANOVA Graph for Participants Who Had Less Than Two Wrong Answers in Task 1A

Table 3. ANOVA Table for Participants Who Had Less Than Two Wrong Answers in Task 1A

Source	SS	df	MS	F	Prob>F
Groups	12108.3	1	12108.3	8.29	0.0066
Error	54045.4	37	1460.7	-	-
Total	66153.7	38	-	-	-

In Task 1B, groups 1, 2 and 3 were significantly different from group 4 with *p-value* = 0.0001 for all participants and with *p-value* = 0.0003 for participants who had less than two wrong answers, indicating that the subtasks performed in the group 4 might be more difficult as shown in Figure 25 and 26. The groups shown in Figure 25 and 26 are not the group of subjects but the subtasks, that is group 1 (subtask 1~3) and 2 (subtask 4~6) were performed by the same subject group (Group 1 in Task 1A), and group 3 (subtask 1~3) and 4 (subtask 4~6) were performed by another (Group 2 in Task 1A). See Tables 4 and 5 for more details. Hence, we also analyzed the difficulty level of each subtask to find out the cause of such results summarized as observation 1 and 2.

- **Task 1B (All participants)**



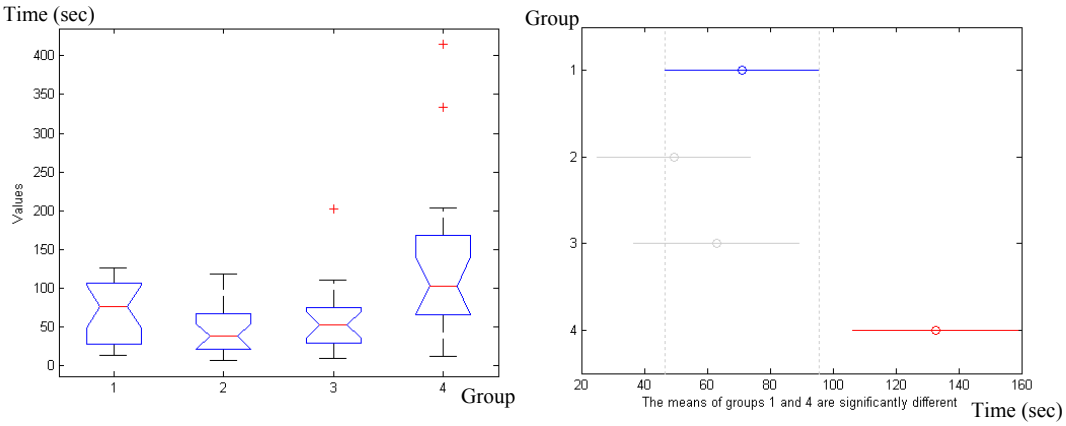
Group 1: highlighting (subtask 1~3), Group 2: hightlighting + spatial (subtask 4~6), Group 3: nothing (subtask 1~3), and Group 4: spatial (subtask 4~6)

Figure 25: ANOVA Graph for All Participants in Task 1B

Table 4. ANOVA Table for all participants in Task 1B

Source	SS	df	MS	F	Prob>F
Groups	76755.8	3	25585.3	7.68	0.0001
Error	366249.1	110	3329.5	-	-
Total	443004.8	113	-	-	-

- **Task 1B (Participants who had less than two wrong answers)**



Group 1: highlighting (subtask 1~3), Group 2: hightlighting + spatial (subtask 4~6), Group 3: nothing (subtask 1~3), and Group 4: spatial (subtask 4~6)

Figure 26: ANOVA Graph for Participants Who Had Less Than Two Wrong Answers in Task 1B

Table 5. ANOVA Table for Participants Who Had Less Than Two Wrong Answers in Task 1B

Source	SS	df	MS	F	Prob>F
Groups	76015.8	3	25338.6	6.96	0.0003
Error	269414.2	74	3640.7	-	-
Total	345430	77	-	-	-

- Observation 1: Different difficulty levels between subtasks

Figure 27 shows the means and distributions through ANOVA analysis for each subtask of Task 1B. In this figure, we found out that the subtasks did not have the same difficulty. Figure 27 (a) and (b) show the result in terms of the elapsed time for subtask 1 to 3 (highlighting) and subtask 4 to 6 (highlighting and spatial) performed by one subject group (Group 1 in Task 1A). Figure 27 (c) and (d) show the result in terms of the elapsed time for subtask 1 to 3 (nothing) and subtask 4 to 6 (spatial) performed by the other subject group (Group 2 in Task 1A). As shown in Figure 27 (b), the subtask 3 was significantly different from the subtasks 1, 4 and 5. In addition, as shown in Figure 27 (d), the subtask 4 was significantly different from the subtasks 1, 2, 3 and 5. This difference of difficulty seemed to affect the total time it took to complete the evaluation.

However, we also found out that subtask 4 showed the best result in terms of a mean time comparison between subjects who used highlighting and subjects who did not. From Figure 27 (b) highlighting group and Figure 27 (d) no-highlighting group, we can see that subtask 4

showed the largest time difference. Therefore, we utilized this analysis to revise Task 1B adjusting the difficulty level of other subtasks to match that of the subtask 4.

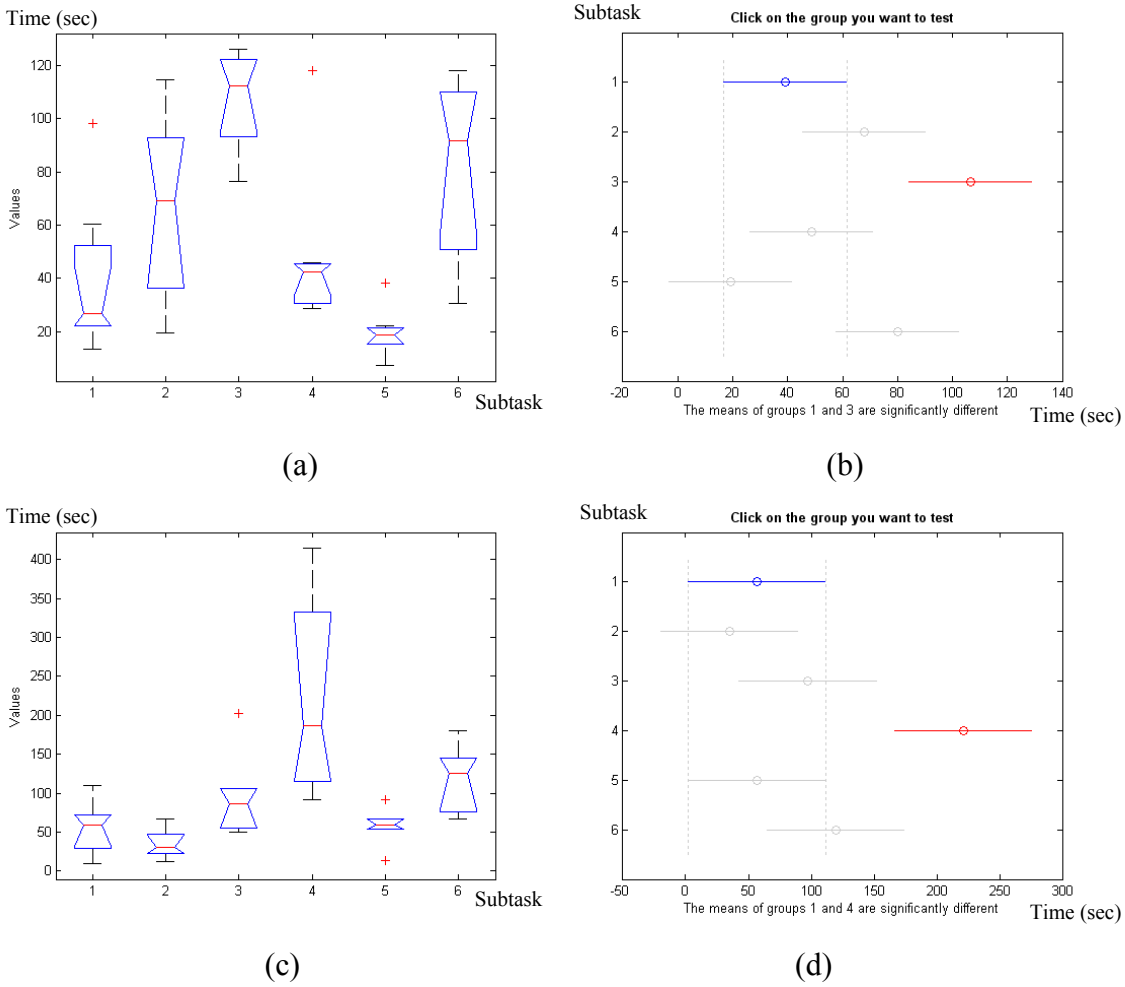


Figure 27: Means and Distributions Through ANOVA Analysis for Task 1B

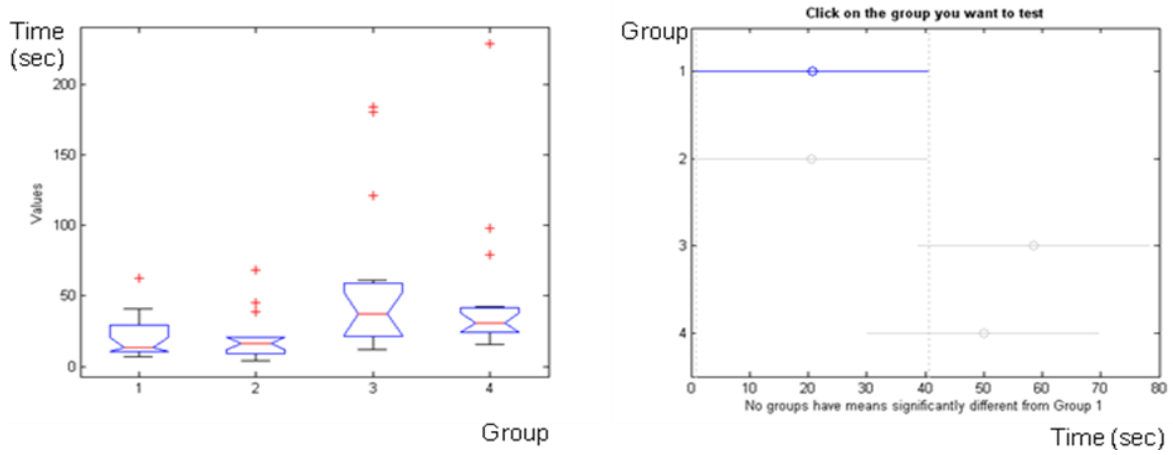
- Observation 2: Different difficulty levels between training and real user study

Some participants felt that the training was much easier than the subtasks of the real user study, and some of the participants started to move the diagram to find the component without noticing that the selected component was located at the same position maintaining spatial information.

From the analysis of the elapsed time for each subtask and subject performance, to refine our user study we made the following refinements: First, we replaced the diagrams for training with diagrams similar to the real data (i.e., having a similar difficulty). Second, we prepared demo videos to show and stress the functionalities of the SDViz to subjects. Finally, we revised the subtasks for Task 1B so that they have the same difficulty levels based on that of the subtask 4.

- **Task 1B (Revised)**

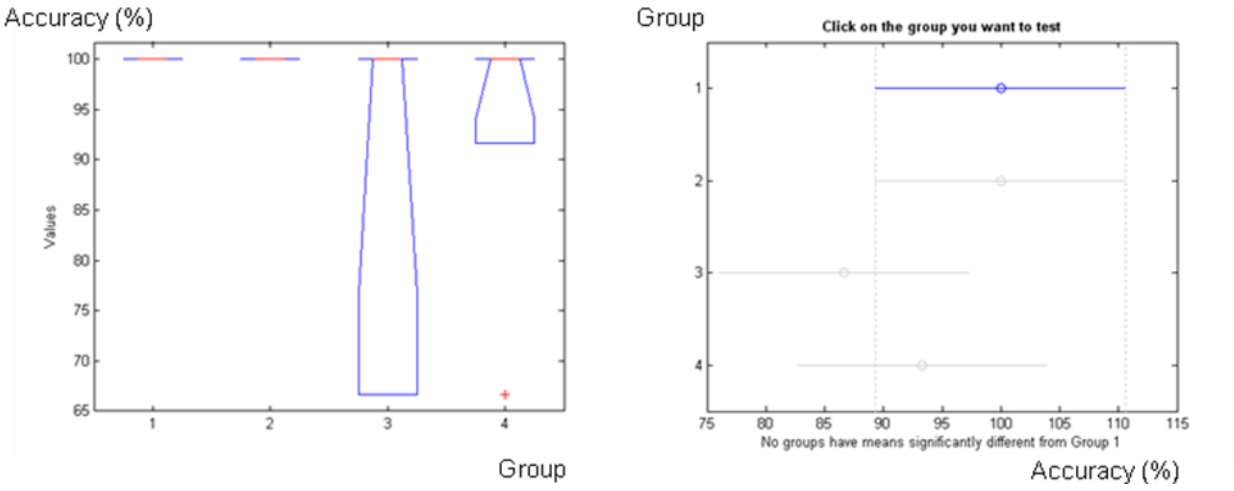
The revised Task 1B ANOVA results are shown in Figures 28 and 29 in terms of mean time and accuracy to complete subtasks respectively. Figure 28 and 29 show that there is no significant difference among the four groups in terms of the mean time with *p-value* = 0.0222 and accuracy with *p-value* = 0.2611. See Tables 6 and 7 for more details.



Group 1: highlighting, Group 2: highlighting + spatial, Group 3: nothing, and Group 4: spatial
Figure 28: ANOVA Graph for Time in Task 1B

Table 6. ANOVA Table for Time in Task 1B

Source	SS	df	MS	F	Prob>F
Groups	17528.1	3	5842.69	3.46	0.0222
Error	94494.9	56	1687.41	-	-
Total	112023	59	-	-	-



Group 1: highlighting, Group 2: hightlighting + spatial, Group 3: nothing, and Group 4: spatial

Figure 29: ANOVA Graph for Accuracy in Task 1B

Table 7. ANOVA Table for Accuracy in Task 1B

Source	SS	df	MS	F	Prob>F
Groups	611.11	3	203.704	1.47	0.2611
Error	2222.22	16	138.889	-	-
Total	2833.33	19	-	-	-

7.1.4 Results and Discussion

Our hypothesis of Task 1 was that highlighting and spatial cues help users to find a component between related documents. In our first evaluation study, results from Task 1A but not Task 1B validated our hypothesis. (The difference between Task 1A and Task 1B is that Task 1A is focusing on highlighting within one diagram, whereas Task 1B deals with highlighting and spatial information maintained between related diagrams.) Based on the observations and lessons learned from the results of Task 1B, we performed the revised Task 1B. (Now, Task 1B means the revised Task 1B). We divided subjects into four groups, and then let them look for a specific component within a diagram or by opening a related diagram. With the logs recorded from Task 1A and Task 1B, we conducted a one-way ANOVA.

The ANOVA graphs for Task 1A showed that the differences in finding a component (e.g., power source) between highlighting and no-highlighting were significant with *p-value* = 0.0118 or 0.0066 (Tabs. 2 and 3) as shown in Figures 23 and 24.

For Task 1B, although we could not see significant differences, we can say that the highlighting groups (Groups 1 and 2) and no-highlighting groups (Groups 3 and 4) seem to have a different

tendency from Figure 28. Another thing we expected from Task 1B was to see the usefulness of the combination of highlighting and spatial cues. Unfortunately, although we did not find significant difference, we could infer that spatial cues will be very dependent on the size (resolution) of a diagram. From Figures 28 and 29, we see there is no difference between Groups 1 (highlighting) and 2 (highlighting + spatial), because most subjects in Group 2 preferred to use highlighting before perceiving spatial information maintained resulting in the same ANOVA graph. For Groups 3 (nothing) and 4 (spatial), subjects in Group 4 liked to look through an entire diagram with a little mouse dragging rather than realizing the spatial cue. Therefore, we understand that the size of diagrams used for Task 1B was too small to determine the usefulness of spatial information maintained between related diagrams.

To summarize, we conclude from our analysis the following:

- To find a component in a diagram, highlighting can be used to provide a very significant cue.
- To find the same component between related diagrams, highlight preservation can be also significant.
- To find the same component between related diagrams, preserving spatial information can be inferred as it can be dependent on the size of diagrams.

7.2 Task 2: Value of Distortion and Transition

7.2.1 Goal and Design

The goal of this task is to evaluate how our visualization methods for technical data help users find the desired information and the users' preference of the visualization methods. The visualization methods include distortion within one diagram and transition between related diagrams. Subjects will find specific information (e.g., components and pins) in diagrams by using each visualization method and answer their preference of the methods. The task will involve several repeated subtask trials.

7.2.2 Scenarios

- **Task 2A**

Task 2A evaluates the visualization method, rectangular fisheye lens, based on the mouse movement, for a distorted view in one diagram compared to a magic lens. Subjects begin the test with a schematic or wiring diagram and are asked to use the two visualization methods (rectangular fisheye lens based on the mouse movement and magic lens) in the diagram to find the desired information, and express their preference for each method.

- **Task 2B**

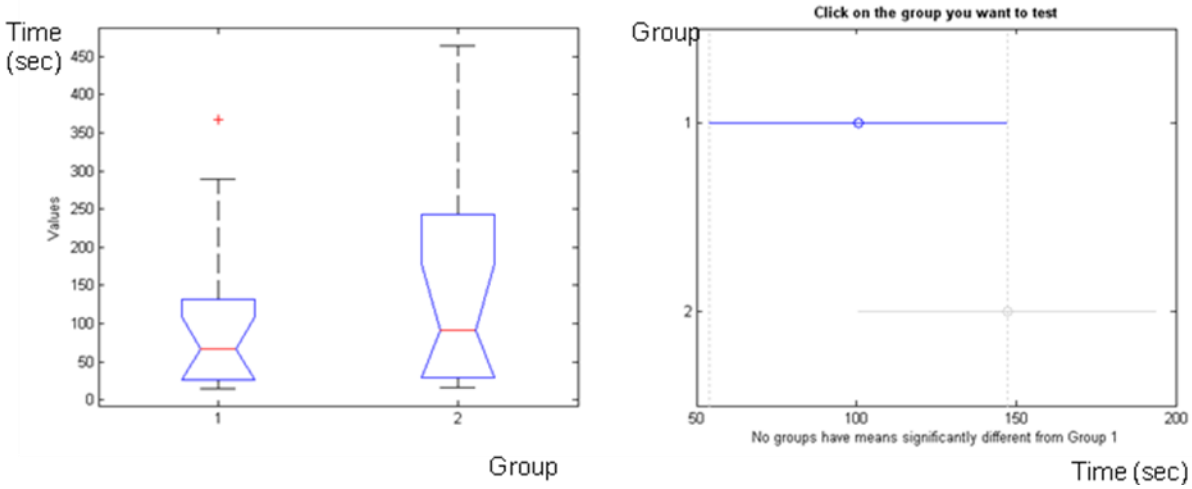
Task 2B evaluates the visualization method, transition-by-blending, for movement between related diagrams compared to simple tabbed window viewing. Subjects begin the test with a

circuit component highlighted in the schematic diagram and are asked to use the two transition methods (transition-by-blending overlaid on a focused component and traditional tabbed window viewing) in order to move to the related diagram and find the desired information and express their preference for each method.

7.2.3 Analysis

- **Task 2A**

The ANOVA results for Task 2A showed that the performance between distortion techniques is not significantly different in terms of mean times to complete subtasks (Fig. 30), whereas there is significance in term of accuracy (Fig. 31).



Group 1: Rectangular fisheye lens, Group 2: Magic Lens

Figure 30: ANOVA Graph for Time in Task 2A

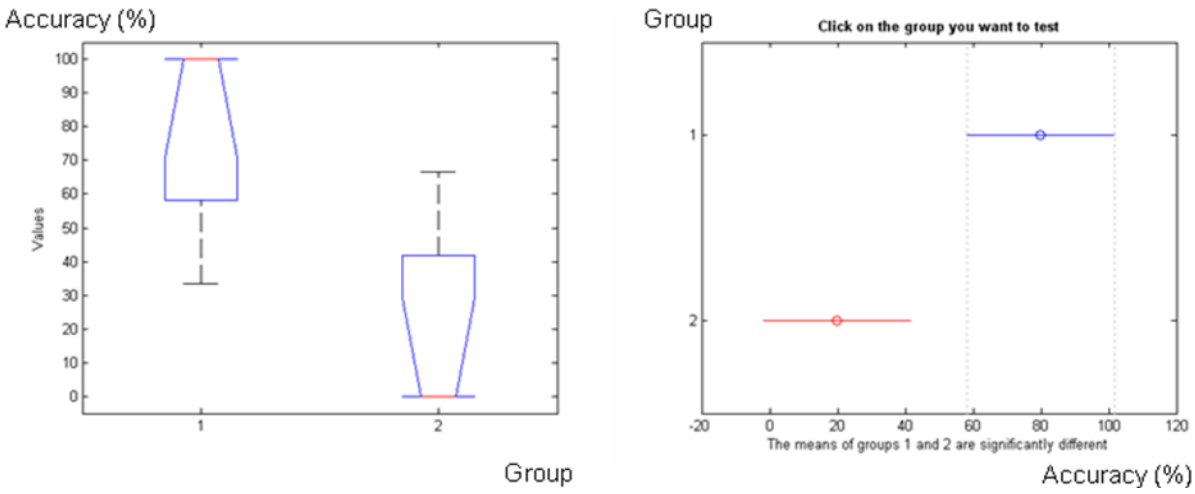
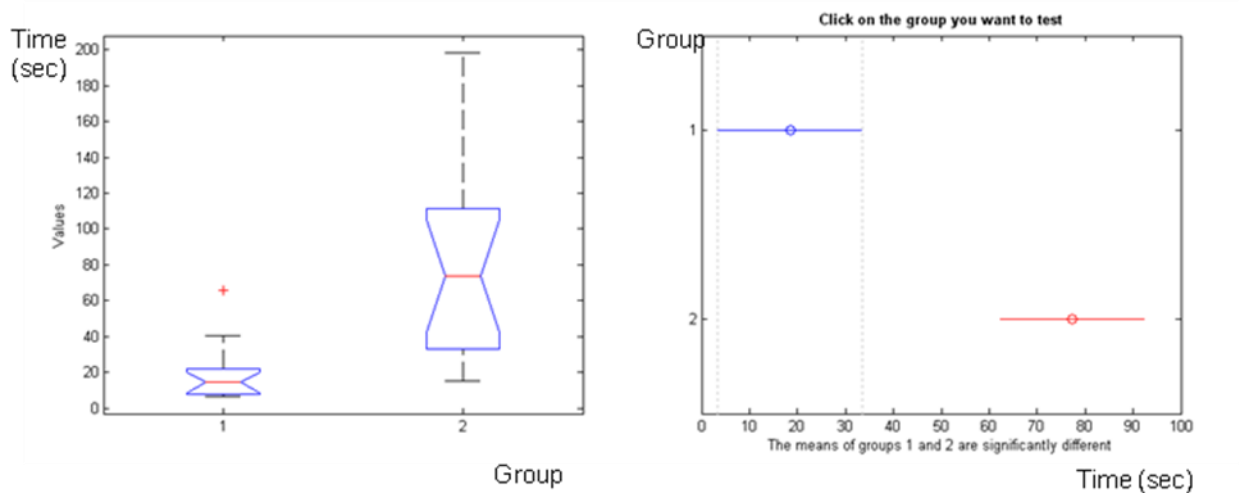


Figure 31: ANOVA Graph for Accuracy in Task 2A

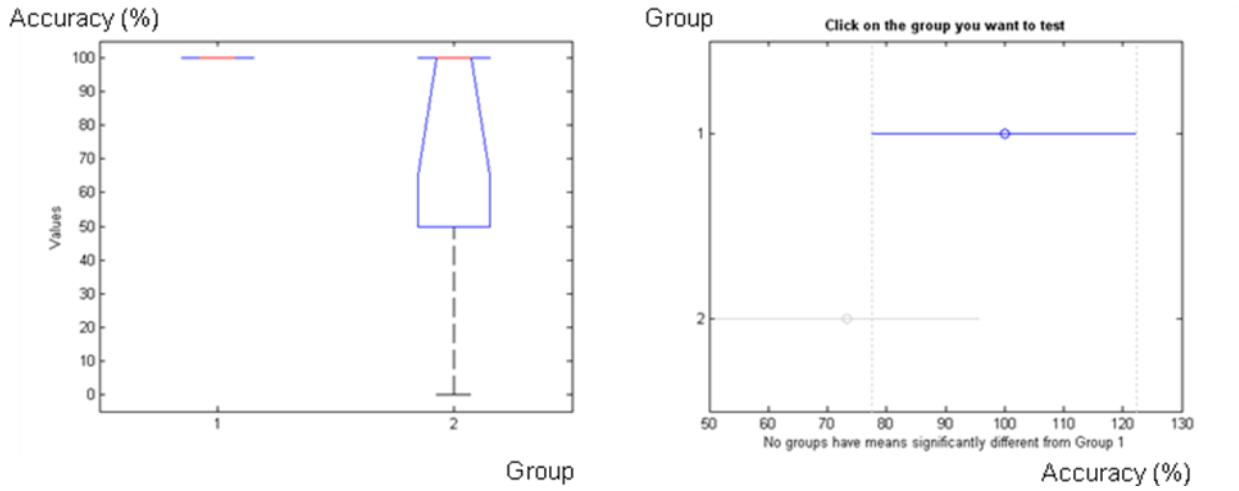
- **Task 2B**

Figure 32, the ANOVA analysis implies that there is significant difference between the transition-by-blending and tabbed interface in terms of time, but there is not in terms of accuracy as shown in Figure 33.



Group 1: Transition by document blending, Group 2: Transition by tab

Figure 32: ANOVA Graph for Time in Task 2B



Group 1: Transition by document blending, Group 2: Transition by tab

Figure 33: ANOVA Graph for Accuracy in Task 2B

7.2.4 Results and Discussion

Our hypothesis of Task 2 was that distortion viewing of a large diagram (such that entire diagram cannot be displayed in a readable resolution) on the small screen helps users navigate the diagram. In particular, unlike a magic lens, a fisheye lens enables users to see more contextual

information while preserving the views of adjacent regions. Our second hypothesis of Task 2 is that the transition of diagrams using animated blending better preserves contextual information when moving to a related diagram. The results from Task 2 showed that our methods using fisheye lens and transition-by-blending are significantly different. We divided the subjects into two groups, and then let them look for a specific component within a diagram or a related diagram. With the logs recorded from Task 2A and Task 2B, we conducted a one-way ANOVA.

The ANOVA graphs for Task 2A show that the differences in finding a component (e.g., pin number) between fisheye lens and magic lens were not significant (*p-value* = 0.3131) (Tab. 8) as shown in Figure 30 in terms of mean time. However, Figure 31 shows they are significantly different in terms of accuracy with *p-value* = 0.013 (Tab. 9).

Table 8. ANOVA Table for Time in Task 2A

Source	SS	df	MS	F	Prob>F
Groups	16337.2	1	16337.2	1.06	0.3131
Error	433539.5	28	15483.6	-	-
Total	449876.6	29	-	-	-

Table 9. ANOVA Table for Accuracy in Task 2A

Source	SS	df	MS	F	Prob>F
Groups	9000	1	9000	10.13	0.013
Error	7111.1	8	888.889	-	-
Total	16111.1	9	-	-	-

For Task 2B, the ANOVA graphs show that the differences in finding the same component between related diagrams were significant in terms of mean time with *p-value* = 0.0004 (Tab. 10) as shown in Figure 32 and in terms of mean accuracy with *p-value* = 0.2073 (Tab. 11) as shown in Figure 33.

Table 10. ANOVA Table for Time in Task 2B

Source	SS	df	MS	F	Prob>F
Groups	26052.4	1	26052.4	16.12	0.0004
Error	45248.6	28	1616		
Total	71301.1	29			

Table 11. ANOVA Table for Accuracy in Task 2B

Source	SS	df	MS	F	Prob>F
Groups	1777.78	1	1777.78	1.88	0.2073
Error	7555.56	8	944.44	-	-
Total	9333.33	9	-	-	-

To summarize, we conclude the following from our analysis:

- To find a component in a diagram, distortion viewing preserving adjacent regions such as fisheye lens can provide significant cues.
- To find the same component between related diagrams, transition-by-blending can be used for significantly faster task completion.

7.3 Task 3: Value of Flow Animation

7.3.1 Goal and Design

The goal of this task is to evaluate how our visualization method, flow animation for technical data, helps users find desired information. The task will involve two repeated trials that will test the value of our flow animation technique in wire tracing.

7.3.2 Scenarios

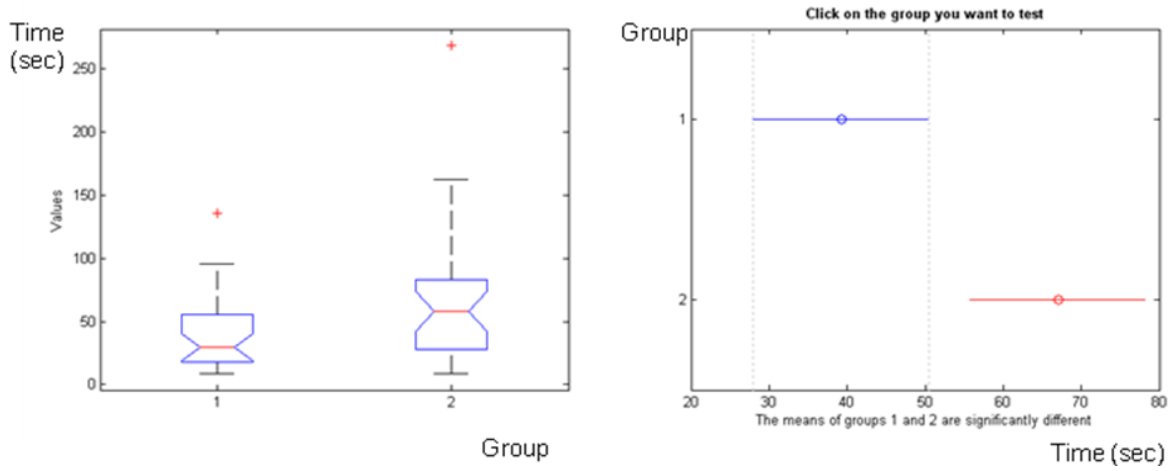
- **Task 3**

Task 3 evaluates the flow animation visualization method compared to simple path highlighting. Subjects begin the test with a circuit component highlighted in the schematic diagram and are asked to follow the path from the highlighted component to another particular component in order to find the desired information and express their preference for each method.

7.3.3 Analysis

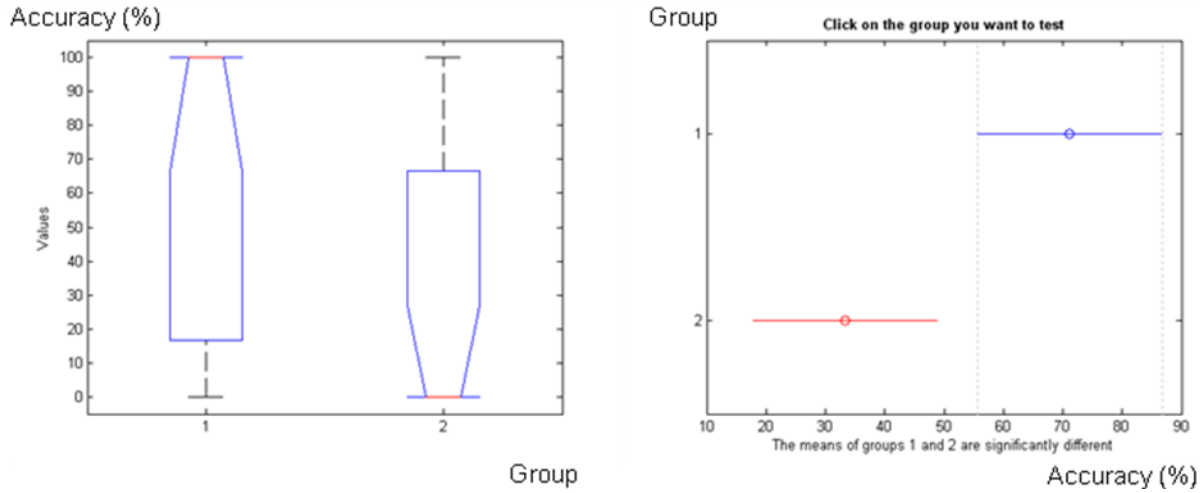
As shown in Figure 34 and 35, the ANOVA graphs imply that there is a significant difference between finding a source component with flow animation and finding one with static connection highlighting in terms of both mean times and accuracy.

- **Task 3**



Group 1: Flow animation, Group 2: static connection highlighting

Figure 34: ANOVA Graph for Time in Task 3



Group 1: Flow animation, Group 2: static connection highlighting

Figure 35: ANOVA Graph for Accuracy in Task 3

7.3.4 Results and Discussion

Our hypothesis of Task 3 was that flow animation would help users find sources and sinks in diagrams by providing directional properties against static connection highlighting. The results from Task 3 showed that flow animation was significantly better in terms of both time and accuracy. We divided subjects into two groups, and then let them look for a source component from flow animation and static connection highlighting provided respectively within a horizontally long diagram. With the logs recorded from Task 3, we conducted a one-way ANOVA.

The ANOVA graphs for Task 3 show that the differences in finding a source component between flow animation and static connection highlighting were significant in terms of time with *p-value* = 0.0166 (Tab. 12) as shown in Figure 34 as well as in term of accuracy with *p-value* = 0.0193 (Tab. 13) as shown in Figure 35.

Table 12. ANOVA Table for Time in Task 3

Source	SS	Df	MS	F	Prob>F
Groups	11567.1	1	11567.1	6.08	0.0166
Error	110279.2	58	1901.4	-	-
Total	121846.3	59	-	-	-

Table 13. ANOVA Table for Accuracy in Task 3

Source	SS	Df	MS	F	Prob>F
Groups	10703.7	1	10703.7	6.17	0.0193
Error	48592.6	28	1735.4	-	-
Total	59296.3	29	-	-	-

To summarize, we conclude the following from our analysis:

- To find a source (or sink) component of flow in a diagram, flow animation can provide very significant cue caused by its directional property.

7.4 Qualitative Task / Analysis / Discussion

In the user evaluation study, we collected surveys from subjects for a qualitative analysis in terms of the usefulness of our visualization techniques. ***(For details, see Appendix C. Feedback by Post-questionnaires).*** Each question has five levels of usefulness (1: Very useful, 2: Useful, 3: No opinion, 4: Not bad, 5: Not useful, or Not Applicable).

- **Highlighting paths**

While finding a power source, participants in Group 1 answered that highlighting a path from a selected component to its power sources helped them find the power source. Figure 36 shows the percentage of subjects who chose each level of usefulness for highlighting the paths. 70 percent of subjects who used highlighting answered it was very useful and 30 percent answered it was useful.

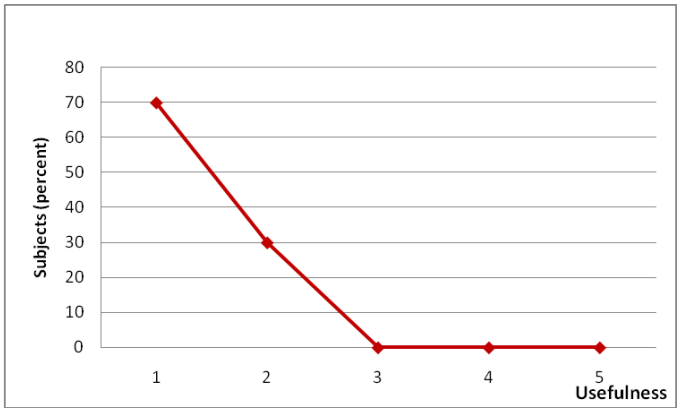
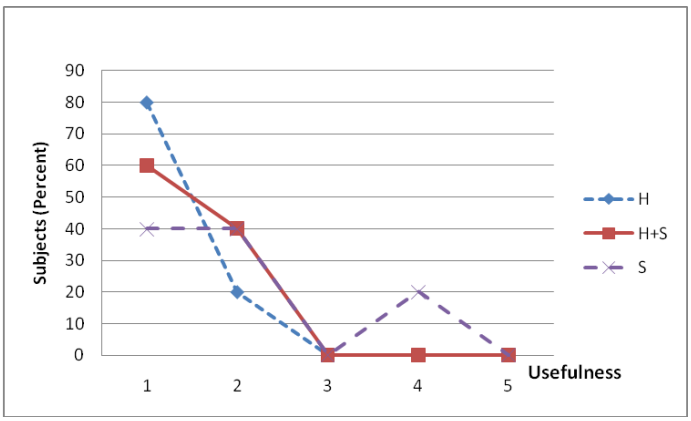


Figure 36: Usefulness for Highlighting Paths (1: Very useful, 5: Not useful)

- **Maintaining contextual information between related diagrams**

Overall, most participants answered that it was easy to find a specific component in related diagrams by using maintained contextual information. Figure 37 shows the percentage of subjects who chose each level of usefulness for maintaining contextual information.



(Highlighting (H), H + Spatial (S), nothing, S)

Figure 37: Usefulness for Contextual Information Maintained (1: Very useful, 5: Not useful)

- **Rectangular fisheye**

Figure 38 shows the percentage of subjects who answered each level of usefulness for rectangular fisheye lens. In this figure, we can see that 40 percent among subjects who used the rectangular fisheye lens answered 1 (Very useful) or 2 (Useful).

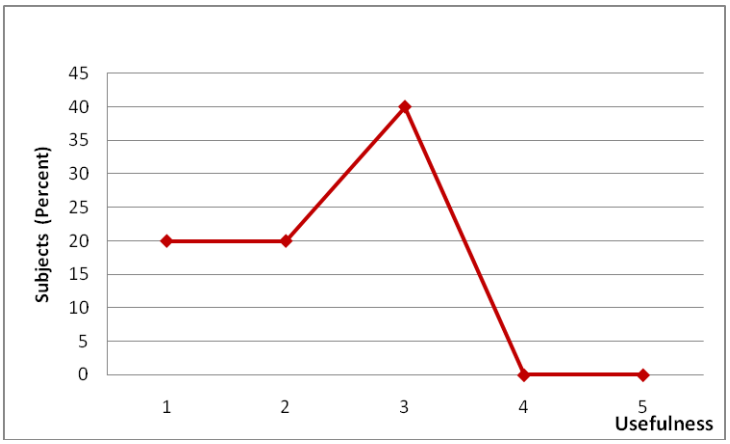


Figure 38: Usefulness for Rectangular Fisheye Lens (1: Very useful, 5: Not useful)

- **Transition-by-blending**

Figure 39 shows the percentage of subjects who chose each level of usefulness for transition-by-blending. In Figure 39, all participants answered it was very useful or useful to complete subtasks finding a specific component in a related diagram.

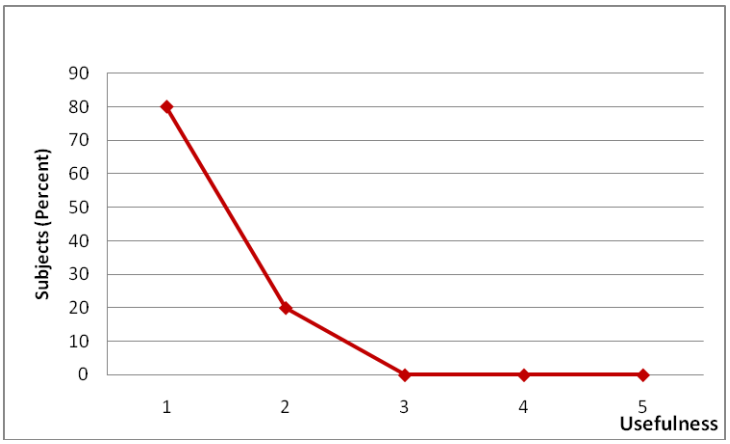


Figure 39: Usefulness for Transition-by-Blending (1: Very useful, 5: Not useful)

- **Flow animation**

All subjects who used flow animation in their tasks answered it helped them to easily find specific components by following the connections. In Figure 40, we can see that 80 percent of subjects felt their tasks were very easy by using flow animation.

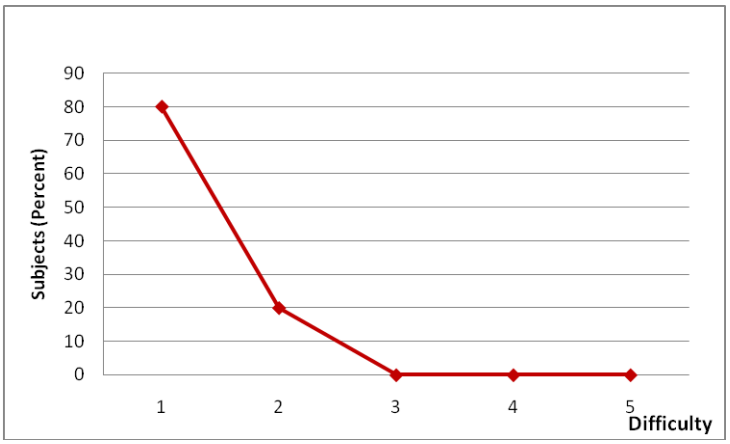


Figure 40: Usefulness for Flow Animation (1: Very easy, 5: Difficult)

8. FIELD EVALUATION

A qualitative field evaluation was conducted with eight aviation technology students at Purdue University to evaluate the value of our visualization techniques in diagnosing a problem with a Boeing 737 aircraft where a cockpit window heater did not function correctly. Subjects were classified into two groups; five subjects used the full functionalities of SDViz to perform the diagnosis after watching tutorial videos as well as self-training with the use of SDViz, whereas three subjects used a PDF viewer to see the diagrams related to the diagnosis. After completion of the task, the first group was given a post-questionnaire to collect qualitative feedback. In the post-questionnaire, we asked subjects for qualitative feedback on the usability (i.e., the characteristic of being easy to use) and usefulness (i.e., the extent to which the software actually helps to solve user's real, practical problems) of each functionality of SDViz.

8.1 Usability

Figure 41 shows the usability results for SDViz functions. Most subjects who used SDViz for the troubleshooting commented that most of the functions were very easy or easy to use. In the case of zoom in and out, one subject stated that it was very difficult to use adding his comment that it would be nice to use the mouse wheel instead of icons to magnify diagrams. For the transition-by-blending, two subjects answered it was not easy because they were not familiar with such an interface.

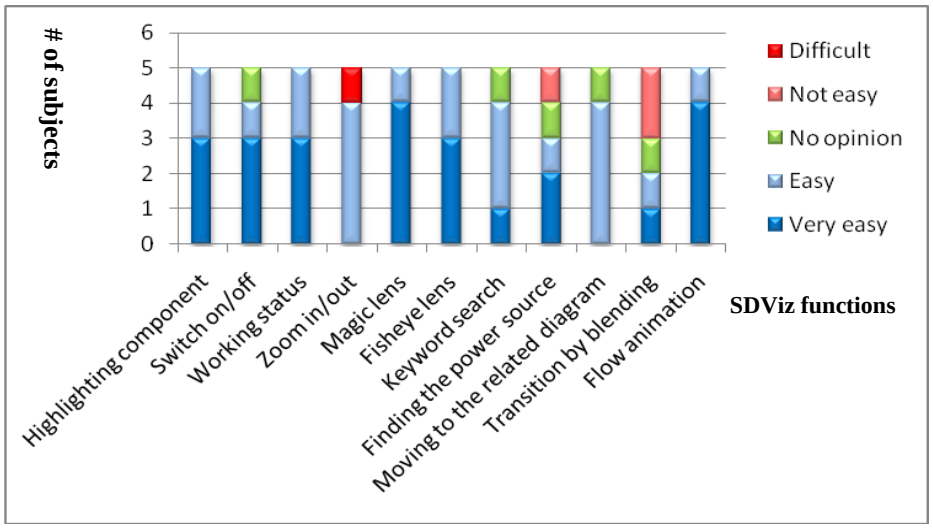


Figure 41: Usability for each Function from Field Study

8.2 Usefulness

Figure 42 shows the usefulness results for each SDViz feature. All subjects who used SDViz for the troubleshooting agreed that the highlighting feature was very useful. Moreover, some of them proposed that it would be nice to highlight more than one component or one link at a time as well as to turn it off. In the cases of the magic lens and the fisheye lens, some subjects commented that they did not use the functions during troubleshooting so that they did not feel the functions are necessary. Usually, subjects used basic zoom in-and-out functions during troubleshooting.

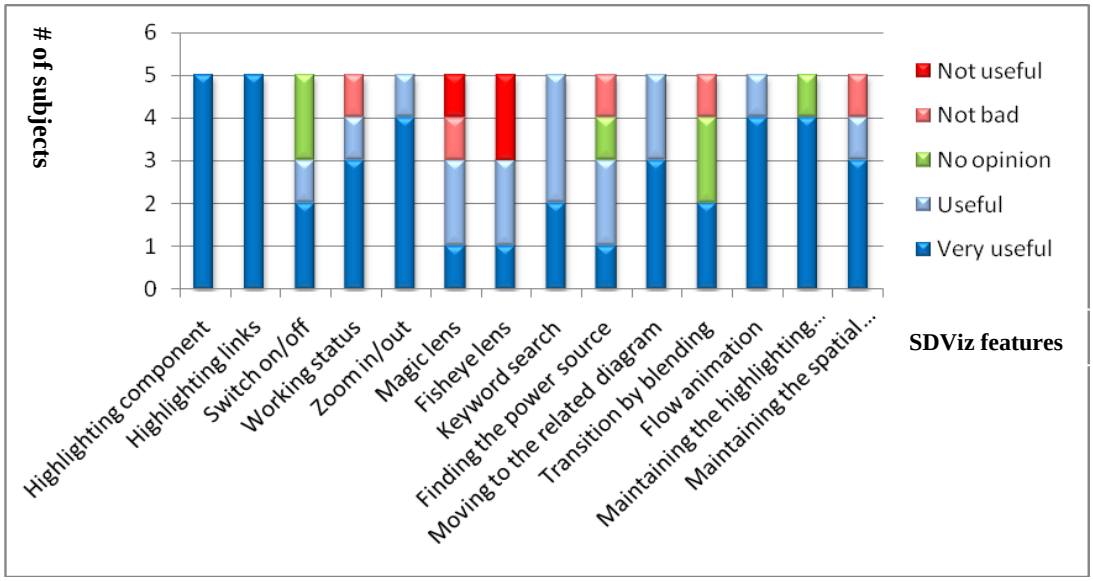


Figure 42: Usefulness for each Feature from Field Study

9. CONCLUSIONS

In this project, we applied various visualization techniques (e.g., highlighting, locating, distortion viewing, blending for transition, and animating) for navigation of technical diagrams in order to help users understand the diagrams as well as find the desired information from them effectively and economically. We had also evaluated the effectiveness of our techniques through the user evaluation study containing several scenarios, which can occur in real trouble shooting procedures. Participants were required to have taken circuit-related courses before and trained to learn how to use the techniques in our SDViz tool. Based on quantitative data recorded during the evaluation study by 49 participants and their qualitative feedback, we analyzed our visualization techniques' performance.

From both quantitative and qualitative analysis, we conclude that highlighting components and links within a diagram (Task 1A) provided users with very significant cues in order to make them find desired information. Maintaining contextual information, such as highlighting (Task 1B) between related diagrams, showed considerable difference although it is not significant for 30 subjects. For maintaining spatial information, such as the location on the screen of a selected component, we did not see significant difference in the analysis results. However, we can infer that such spatial cue maintained will play an important role from the analysis of Task 2B because transition by blending, we proposed, supports essentially the maintaining of spatial information by fixing the location of a selected component as an origin for blending diagrams. For the distortion viewing (Task 2A) and transition by blending (Task 2B), we found they were significant for both quantitative and qualitative analysis. In terms of accuracy, distortion viewing will be helpful when very large diagrams are needed to be displayed on a small screen as providing both a readable resolution for the area of interest and an overview for adjacent regions. Transition-by-blending can also be certainly useful for inter-diagram navigation in terms of time to find the same component. The flow animation (Task 3) made us recognize the importance of directional information for diagrams including complex link connections by showing significant differences against static connection highlighting in terms of time and accuracy.

The results (Figure 41 and Figure 42) from the field evaluation performed by aviation technology students at Purdue University showed that the functionalities of SDViz were very useful during troubleshooting of aircraft maintenance and repair tasks. Moreover, the user interface was easy for them to use after watching a tutorial video (10 minutes) and practicing with the system (about 15 minutes). Although the purpose of this field evaluation was to collect qualitative feedback, we also observed the troubleshooting time. Subjects who used a PDF viewer took about 17 ~ 32 minutes to find possible causes spending most of their time in finding related diagrams to the schematic diagram or maintenance manual, whereas subjects who used our system took about 9 ~ 15 minutes to complete the troubleshooting.

In conclusion, we believe that various visualization techniques provided by our SDViz can help users progress their tasks with which technical data, such as schematic and wiring diagrams, are

dealt. Based on the analysis from the user evaluation study and field study, we also believe that such techniques will significantly affect the performance of users in terms of either time or accuracy.

10. FUTURE RESEARCH/CONSIDERATIONS

We have several issues to be considered as future work such that SDViz is utilized as a more efficient tool for people who are learning maintenance as well as working in the troubleshooting processes of aircrafts. First, we can consider improving the capability of interoperations between various units such as components, pages, diagrams, subsystems, and systems. Such interoperations can help maintainers understand the current trouble with a broad point-of-view about an entire system and cooperate with other maintainers. Second, integration with multimedia data like 3D models, flashes, and video clips will make SDViz be very effective for maintenance troubleshooting. Each component or subsystem can be displayed with 3D models providing users with a variety of interactive operations such as interactive viewpoints, internal 3D views, and assembly [Ref. 7] as well as on/off operations. Flashes may also be used for similar interactive operations. Video clips will provide useful information to refer how to work with each component and subsystem. Third, as we verified through the user evaluation study, the distortion viewing of technical data in order to stress the region-of-interest was effective in finding desired information in large diagrams. Hence, more focus+context techniques are needed to be developed in order to deal with technical data containing various complexities. Finally, using touch screen including multi-touch screen can be considered for users to provide more intuitive interfaces and interactions.

11. References

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APPENDIX A

User Evaluation Study Plan

Novel Presentation Methods for Technical Data

1. INTRODUCTION

We will conduct an evaluation study to test our proposed novel presentation methods for technical data using our SDViz application. This user study will be comprised of structured interviews and three small task simulations in order to evaluate the effectiveness of several visualization methods.

- **Task 1**: Maintaining contextual information between related schematic/wiring diagrams by highlighting techniques
- **Task 2**: Maintaining context using distortion viewing vs. tabbed browsing
- **Task 3**: Showing current flow direction vs. just highlighting links

1.1 Evaluation Methods

User mouse clicks and timing information will be collected for the total task and for each sub-step for use in statistical evaluation. Additionally, participants will complete a questionnaire for qualitative feedback. See Appendices A, B, and C for more information on the information that will be recorded.

1.2 Experimental Design

Subjects will perform repeated trials for each task. A preliminary user study will be conducted to ensure that the trials are of equal complexity and to determine the amount of cross subject variation. If the cross-subject variation is too high, subjects will perform both the base case and advanced case trials in a random order.

Prior to the experiment, subjects will be given a pre-test to determine their skill level. Subjects who do not possess rudimentary efficiency in using schematics will not participate in the full

experiment. Once a subject passes the pre-test, they will perform a training task to familiarize themselves with the systems functionality. During the training, subjects may ask questions and receive guidance in the use of the system. Once the training is complete, subjects will complete the experiments described in Section 2 (Task 1) [or Section 3 (Task 2), Section 4 (Task 3]). The order of the repeated trials and tasks will be randomized using a magic square method.

2. EVALUATION STUDY: TASK 1

2.1 Goal

The goal of this task is to evaluate how our visualization methods for technical data help users find desired information. The task will involve several repeated subtask trials that will test the value of our highlighting techniques in wire tracing and in maintaining context when moving from a schematic diagram to the corresponding wiring diagram.

2.2 Scenario

The users will be asked to perform two subtasks (Tasks 1A and 1B). Each subtask has several trials:

- **Task 1A (See Appendix B-3 for exact repeated trial details.)**

  Subjects will begin the test with a circuit component highlighted and will be asked to locate the 115V AC power source.

  At this point, subjects in Group A will see the path to power sources connected to the component automatically, while subjects in Group B do not.

  When the subjects find the power source, they will double click on the circuit component indicating that the subtask is complete. Timing, mouse clicks, and location methods for this subtask will be recorded and used for analysis.

- **Task 1B (See Appendix B-3 for exact repeated trial details.)**

  Subjects will begin the test with a circuit component highlighted in the schematic diagram and will be asked to open the related wiring diagram and find a specified pin connection in the related wiring diagram.

  At this point, subjects in Group A will see the component highlighted in the related wiring diagram, whereas subjects in Group B will need to find the component in the wiring diagram, again because no contextual information is maintained.

3. EVALUATION STUDY: TASK 2

3.1 Goal

The goal of this task is to evaluate how our visualization methods for technical data helps users find desired information and the users' preferences of the visualization methods. The visualization methods include distortion within one diagram and transition between related diagrams. Subjects will find specific information (e.g., components and pins) in diagrams by using each visualization method and answering their preferences of the methods. The task will involve several repeated subtask trials.

3.2 Scenario

The users will be asked to perform two subtasks (Tasks 2A and 2B). Each subtask has three trials:

- **Task 2A (See Appendix C-3 for exact repeated trial details.)**

Task 2A is to evaluate the visualization method, rectangular fisheye lens based on the mouse movement, for a distorted view in one diagram compared to a magic lens.

Subjects will begin the test with a schematic or wiring diagram and will be asked to use the two visualization methods (rectangular fisheye lens based on the mouse movement and magic lens) in the diagram to find the desired information, and express their preferences for each method.

The features of each method are as follows:

- Rectangular fisheye lens based on the mouse movement distorts adjacent areas of a focus region in order to see broad adjacent context in a small area, when the speed of the mouse movement is less than a threshold.
- Magic lens magnifies a fixed-size area causing occlusion of adjacent neighbors.

- **Task 2B (See Appendix C-3 for exact repeated trial details.)**

Task 2B is to evaluate the visualization method, transition-by-blending, for movement between related diagrams compared to simple tabbed window viewing.

Subjects will begin the test with a circuit component highlighted in the schematic diagram and will be asked to use the two transition methods (transition-by-blending overlaid on a focused component and traditional tabbed window viewing) in order to move to the related diagram and find the desired information and express their preferences for each method.

The features of each method are as follows:

- Transition-by-blending can be used to see the information from the related diagram with a varying blending ratio as well as move to the related diagram while preserving the spatial context of the focused component without opening the related diagram explicitly.
- Traditional tabbed window viewing is used to move between opened diagrams.

4. EVALUATION STUDY: TASK 3

4.1 Goal

The goal of this task is to evaluate how our visualization method, flow animation, for technical data help users find desired information. The task will involve two repeated trials that will test the value of our flow animation technique in wire tracing.

4.2 Scenario

The users will be asked to perform one subtask (Task 3). The subtask has two trials:

- **Task 3 (See Appendix C-3 for exact repeated trial details.)**

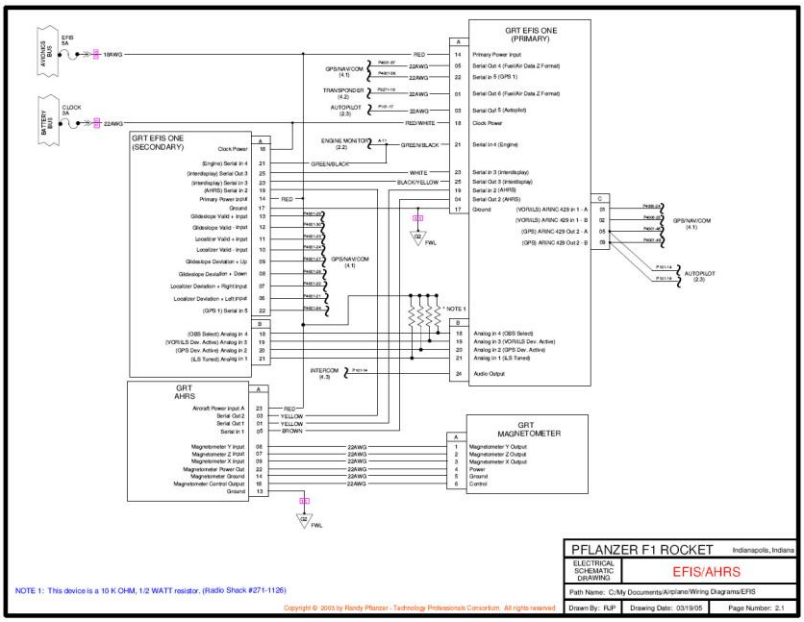
Task 3 is to evaluate the flow animation visualization method compared to simple path highlighting.

Subjects will begin the test with a circuit component highlighted in the schematic diagram and will be asked to follow the path from the highlighted component to another particular component in order to find the desired information and express their preferences for each method.

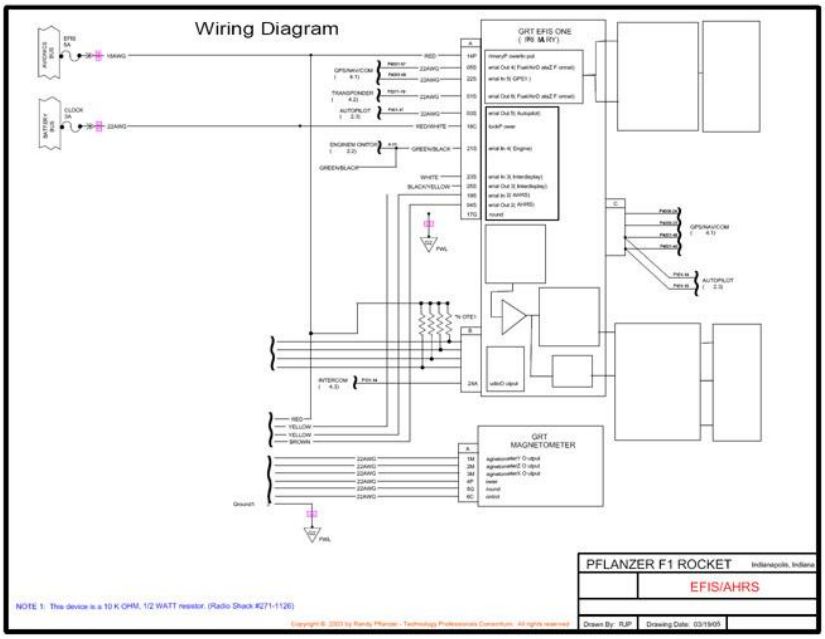
Appendix A-1-a. Training Diagrams 1

For Task 1, two diagrams are used for training of SDViz collected from the source mentioned below the diagram. *(The wiring diagram was modified from the schematic diagram for the purpose of this training.)*

<Schematic diagram>



<Wiring diagram>

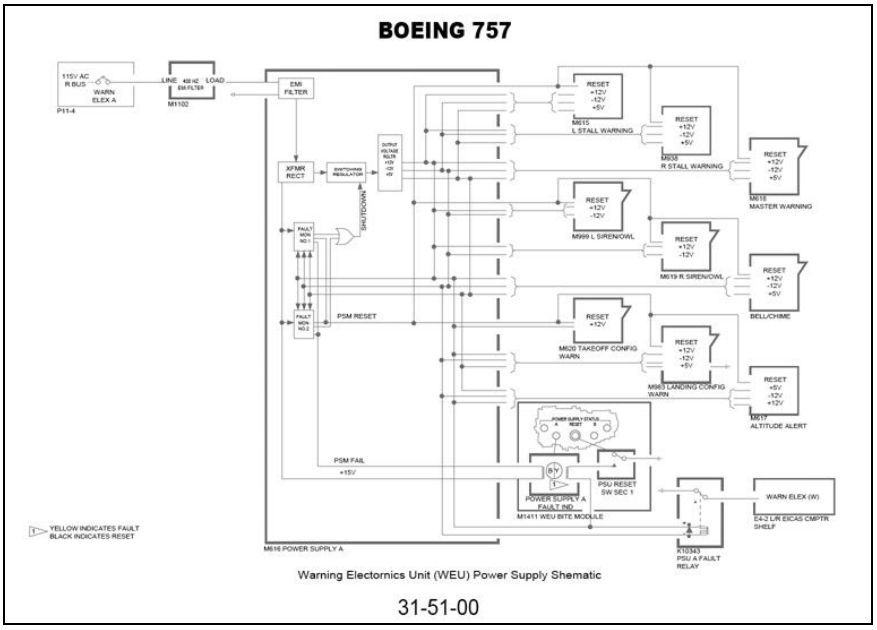


(Source: http://www.pflanzer-aviation.com/PDF%20Files/EFIS.pdf)

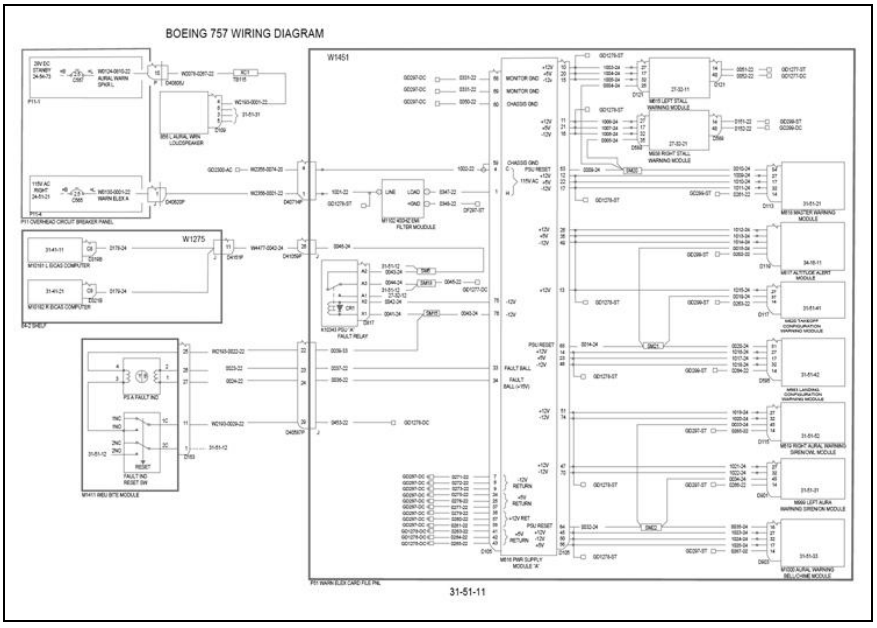
Appendix A-1-b. Training Diagrams 2

For Task 2 and Task 3, two diagrams photocopied from the Boeing 757 maintenance and wiring diagram manuals and created with a vector graphics drawing tool are used for training of SDViz. *(Diagrams were trivially modified from the original diagram for the purpose of this training.)*

<Schematic diagram>



<Wiring diagram>



(Source: Boeing757 Maintenance and Wiring diagram manual in Aviation Library at Purdue University)

Appendix A-2. Pre-task questionnaire

Evaluation Study: Novel Presentation Methods for Technical Data

The following questions will be used to collect information on your background. Please mark Yes or No, or write down your answer.

Q0. **[Optional]** Gender (Female/Male)

Q1. Are you color blind? (Yes/No)

- If you answer "Yes", choose your color blindness type.
  - o Red-green ( )
  - o Blue-yellow ( )
  - o I don't know my color blindness type . ( )

Q2. What is your major? (EE/CE/Aviation/Others: _____)

Q3. How often do you use a computer?

- Several hours most days ( )
- Almost daily ( )
- 1-2 per week ( )
- 1-3 per month ( )
- A few times ( )
- Never ( )
- Others (_____)

Q4. Are you familiar with viewing PDF files using Adobe Acrobat? (Yes/No)

Q5. Have you ever taken any introductory Electrical Engineering (EE) courses in which you used schematic or wiring diagrams? (Yes/No)

- If you answered "Yes", please write the code of the class (if possible) and the year you took. If you took multiple classes, give the most recent courses.
  - o Code: _____, Year: _____
  - o Code: _____, Year: _____
  - o Code: _____, Year: _____

Q6. Do you have any experiences using schematic or wiring diagrams of aircraft? (Yes/No)

- If you answered "Yes", please mark the years of experience working with aircraft schematic or wiring diagrams.
  - o Less than 6 months ( )
  - o 6 months ~ 1 year ( )
  - o 1 year ~ 2 years ( )
  - o 2 years ~ 3 years ( )
  - o More than 3 years ( )

Appendix B-1. Evaluation Methods for Task 1

1. Subjects

Subjects participating in the evaluation study for Task 1 should have completed an introductory Electrical Engineering (EE) course but require no aircraft knowledge. All subjects are classified into two groups: Group A and B. Each group performs procedures in "Instructions for Task 1," after completing the system training.

2. Pre-interview

In order to evaluate each subject's background knowledge and skill level, each subject will answer the questions provided in the Pre-task Questionnaire.

3. Training

For Task 1, each subject will be trained in the use of SDViz. The training small-tasks will contain the following operations;

- Highlight a component to make it focused
- Move to related wiring diagrams
- Use tabbed interface to move between opened documents
- Find the pin number

(The following operations are only available for the SDViz that the subjects in Group A use. Subjects in Group B will skip the training for the following functions.)

- Find the power source
- Maintain contextual information (e.g., highlighting) between related diagrams

4. Pre-test

After training, subjects will answer the questions (Appendix B-2 Evaluation questions) provided in the Evaluation questions of training for Task 1 to determine whether or not they can perform the evaluation study.

5. Post-interview

After completing the evaluation study, subjects will complete a Post-task Questionnaire.

6. Observation Methods

For Task 1, two factors are recorded: time and mouse clicks.

- **Time:** This factor can be used to see how fast subjects achieve each substep and an entire task. Two types of time durations (e.g., each substep duration and total task duration) are saved in milliseconds whenever a user performs the given instruction for each substep and an entire task. For the data acquired from Group A and Group B, mean values for each substep and total task duration are calculated and compared.

- **Mouse clicks:** This factor can be used to see how fewer actions subjects utilize to achieve each substep and an entire task. Several types of mouse clicks during substep and entire task completion are saved as an integer number whenever a user clicks. Details of mouse events are explained in **Section 7. Data Collection**. For the data acquired from Group A and Group B, mean values for the number of mouse clicks during each substep and total task duration are calculated and compared.

For analysis of the evaluation results, Task 1B is classified into four categories.

- Category 1 (Tasks 1B-1~1B-3): Group A performs this by using highlighting.
- Category 2 (Tasks 1B-4~1B-6): Group A performs this by using highlighting and spatial information maintained.
- Category 3 (Tasks 1B-1~1B-3): Group B performs this by only simple viewing of diagrams.
- Category 4 (Tasks 1B-4~1B-6): Group B performs this by using spatial information maintained.

	Tasks 1B-1 ~ 1B-3	Tasks 1B-4 ~ 1B-6
Group A	Highlighting	Highlighting + Spatial information
Group B	-	Spatial information

cf. The revised Task 1B has only three subtasks (Task 1B-1, Task 1B-2, Task 1B-3), so, above should be changed as follows. Subjects will be classified into four groups. (Group A, Group B, Group C, Group D)

For analysis of the evaluation results, Task 1B is classified into four categories, and subjects in each group will perform each category.

- Category 1: Group A performs this by using highlighting.
- Category 2: Group B performs this by using highlighting and maintained spatial information.
- Category 3: Group C performs this by only simple diagram viewing (base case).

- Category 4: Group D performs this by using maintained spatial information.

Highlighting	Highlighting + Spatial information
-	Spatial information

Therefore, we can compare the effect of highlighting between Groups A and C as well as Groups B and D. For the comparison of the effect of maintained spatial information, it can be shown between Groups A and B as well as Groups C and D.

7. Data Collection

All the user interactions (e.g., mouse click/release, menu selection) are recorded with their time stamps, interaction IDs, selected items related to the interactions, and the application modes. The user interaction types are as follows:

Interaction Type	Description
SELECT_MENU	• It is stored whenever a user selects a function item from the program menu, toolbar, and context menu.
PICK_OBJECT	• It is stored whenever a user double clicks on an object or clicks the right button for seeing a context menu.
MOUSE_ENTER	• It is stored whenever the mouse cursor moves on an object.
MOUSE_EXIT	• It is stored whenever the mouse cursor moves out from an object.
MOUSE_LDOWN MOUSE_RDOWN	• It is stored whenever the mouse button is clicked.
MOUSE_MOVE	• It is stored whenever the mouse cursor moves.
MOUSE_LUP, MOUSE_RUP	• It is stored whenever the mouse button is released.

Appendix B-2-a. Evaluation questions (Task 1 Training) ***(Group A)***

Evaluation Study: Novel Presentation Methods for Technical Data

The following questions will test your training status. Please mark or write down your answer for the following questions.

Q1. Using our system, what actions must be performed in order to focus/highlight a component?

1) Left click on a component ( )
2) Right click on a component ( )
3) Middle button click on a component ( )
4) Mouse over a component ( )

Q2. What actions must be performed in order to move to the related wiring diagram?

1) Left click the mouse button and select “Link” ( )
2) Right click the mouse button and select “Link” ( )
3) Double click on any position ( )
4) Mouse over a component and select “Link” ( )

Q3. What actions must be performed to find the power source of a component in our system?

1) Left click on a component and select “Link” ( )
2) Right click on a component ( )
3) Left click on a background ( )
4) Mouse over a component ( )

Q4. What information is maintained between related diagrams?

Appendix B-2-b. Evaluation questions (Task 1 Training) ***(Group B)***

Evaluation Study: Novel Presentation Methods for Technical Data

The following questions will test your training status. Please mark or write down your answer for the following questions.

Q1. Using our system, what actions must be performed in order to focus/highlight a component?

1) Left click on a component ( )
2) Right click on a component ( )
3) Middle button click on a component ( )
4) Mouse over a component ( )

Q2. What actions must be performed in order to move to the related wiring diagram?

1) Left click the mouse button and select “Link” ( )
2) Right click the mouse button and select “Link” ( )
3) Double click on any position ( )
4) Mouse over a component and select “Link” ( )

Appendix B-2-c. Answers for Evaluation questions (Task 1Training)

Evaluation Study: Novel Presentation Methods for Technical Data

Q1 ~ Q2 are common answers, and Q3 ~ Q4 are only for Group A.

Q1. Using our system, what actions must be performed in order to focus/highlight a component?

1) Left click on a component ( )
2) Right click on a component ( )
3) Middle button click on a component ( )
4) Mouse over a component (O)

Q2. What actions must be performed in order to move to the related wiring diagram?

1) Left click the mouse button and select “Link” ( )
2) Right click the mouse button and select “Link” (O)
3) Double click on any position ( )
4) Mouse over a component and select “Link” ( )

Q3. What actions must be performed to find the power source of a component in our system? (Find two answers)

1) Left click on a component and select “Link” ( )
2) Right click on a component ( )
3) Left click on a background ( )
4) Mouse over a component (O)

Q4. What information is maintained between related diagrams?

Highlighting, **Focusing, Selection**, **Spatial** information, or **Position** of a focused component

Appendix B-3-a. Instruction sheet for Task 1 *(Group A)*

Evaluation Study: Novel Presentation Methods for Technical Data

Hello, and welcome to this evaluation study. Please refer to this document during your experiment, as it will provide you with all necessary instructions for completing your task. Whenever you are not sure about the task or if you do not feel comfortable at any time during the experiment, please TELL us.

Your task

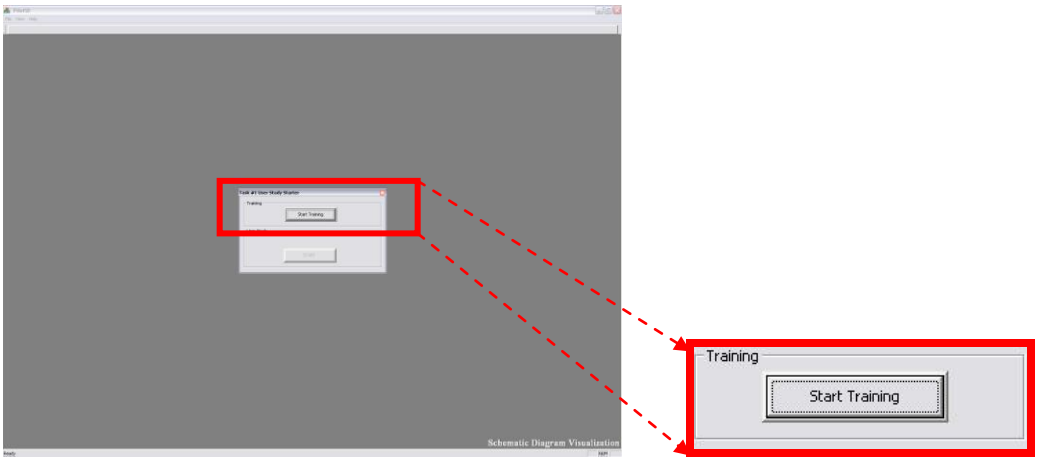
During this experiment you will be asked to find different components in various diagrams per the written instructions. The system will log the timing and mouse clicks and movement information. The goal is to find the component as quickly as possible while maintaining 100 percent accuracy.

How to use SDViz?

Before starting this evaluation study, you will be trained in the use of SDViz. Please read the instructions detailing the SDViz features and complete the training tasks. When you feel comfortable with the system you will be asked to take a short quiz. You must score 100 percent on this quiz in order to continue on to the experiment. You may take as long as you feel necessary for training.

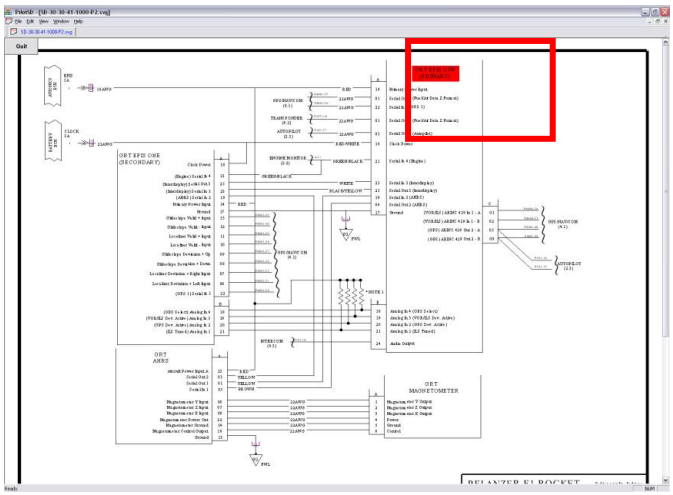
<Training Instructions>

First, click the "Start Training" button in the initial dialog, Task 1 User Study Starter.



<Initial Screenshot>

You will start our training using the schematic diagram containing the component (“GRTEFIS ONE [PRIMARY]”) highlighted in red.

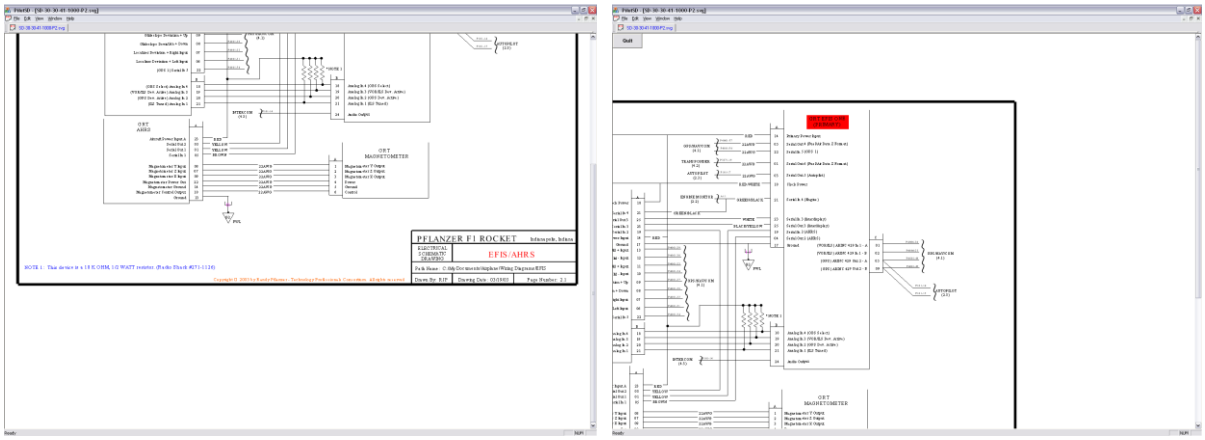


<Initial highlighting for training>

1) Scrolling/panning a diagram

You can scroll or pan a diagram to transform the view. To scroll a diagram, use the vertical scroll bar on the right side of the SDViz. To pan a diagram, you can left click and hold the mouse button dragging a diagram.

1. Scroll or pan a diagram to make the view like figures below.

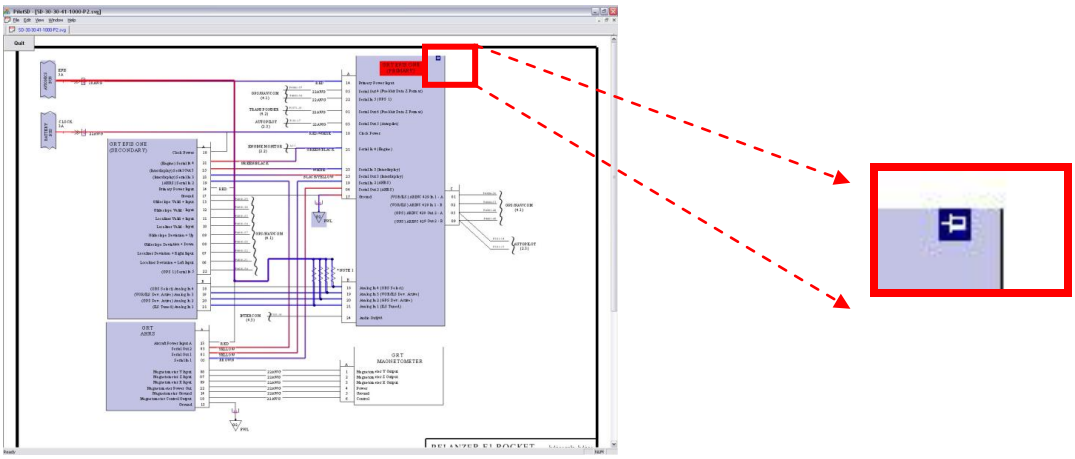


<View transform by scrolling (left) and panning (right) a diagram>

2) Highlight a component and a link

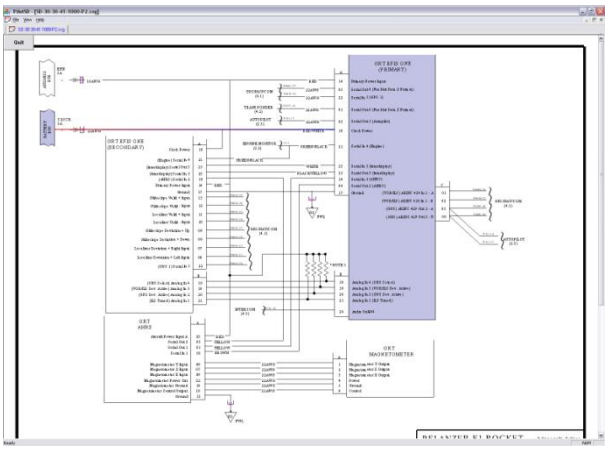
Place the mouse cursor on a component or a link in the diagram (you don't need to click any mouse buttons). The component is focused with a pin icon ( ) in its upper right corner and highlighted in light purple. The link is highlighted in color changing from red to blue making two end-components highlighted. These highlightings will be maintained while moving and holding the left mouse button.

1. Move the mouse cursor to the component "GRTEFIS ONE (PRIMARY)", and see the component highlighted.
2. Hold the left mouse button on the component "GRTEFIS ONE (PRIMARY)", and move the mouse.



<Highlight a component>

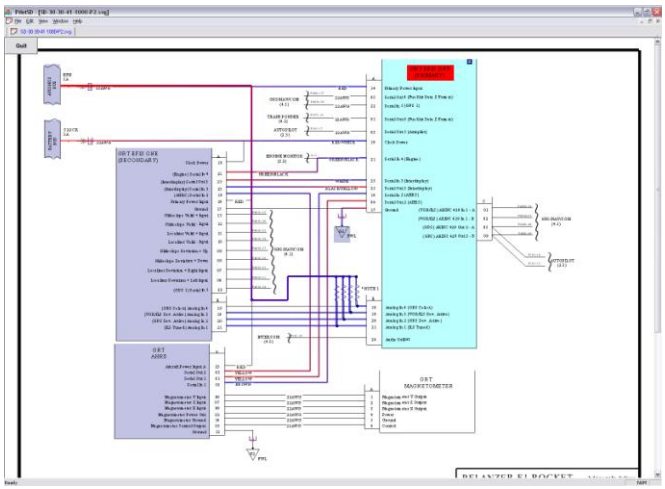
1. Move the mouse cursor to the link connecting "GRTEFIS ONE (PRIMARY)" and the "Battery Bus" like the figure below.
2. Hold the left mouse button on the link, and move the mouse.



<Highlight a link>

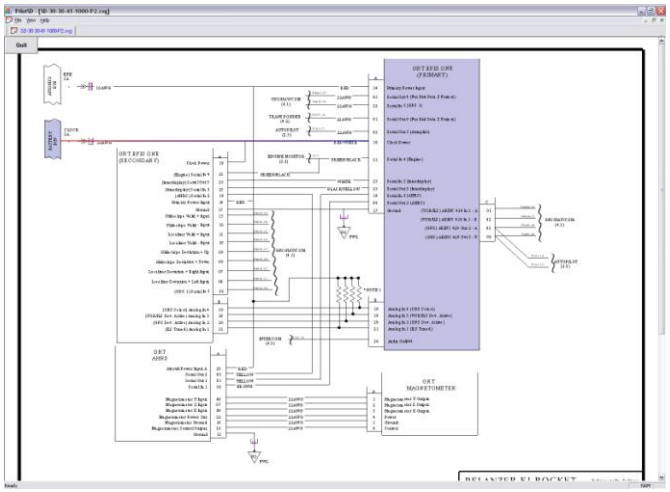
During the training and user test, you will also use the highlighting by double click to answer each subtask, and you should see the component highlighted in cyan. You can also double click a link but the highlighting color of a link will be the same.

1. Double click the “GRTEFIS ONE (PRIMARY)”, and confirm that the highlight color of the component is changed.



<Double click a component>

2. Double click the link connecting “GRTEFIS ONE (PRIMARY)” and the “Battery Bus”.



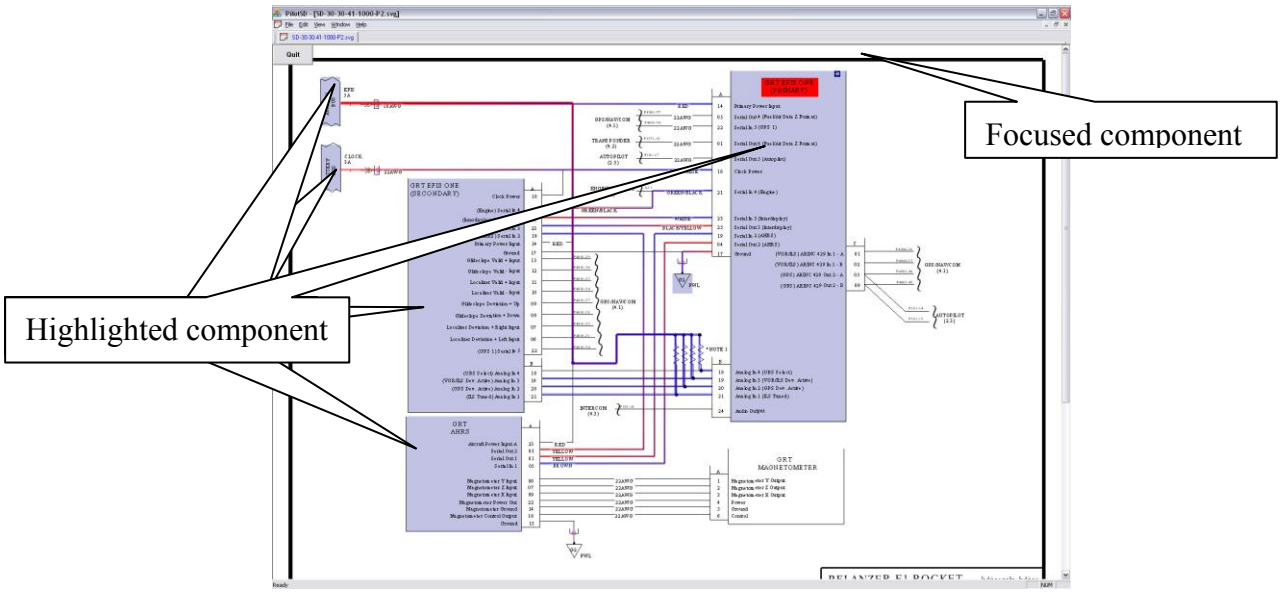
<Double click a link>

3. Double click the mouse button on any position of the background of the diagram to release it.

3) Highlighting vs. focusing

You must have understood the difference between highlighting and focusing a component. Check the figure below to help remind you of the difference.

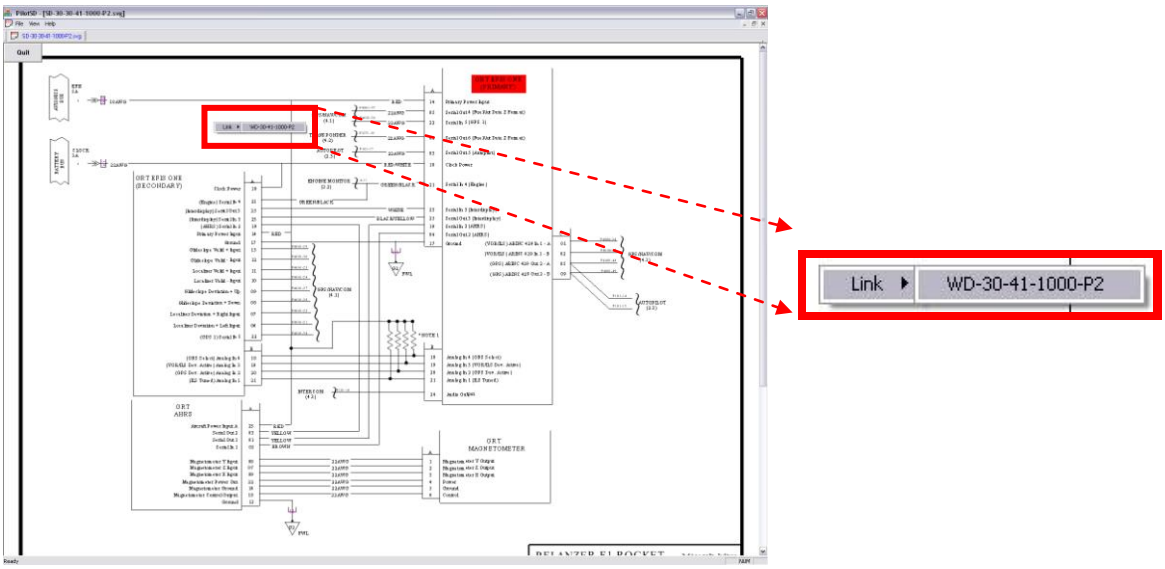
In this figure, five components have been highlighted in light purple, and one of them has been focused with the pin icon ( ).



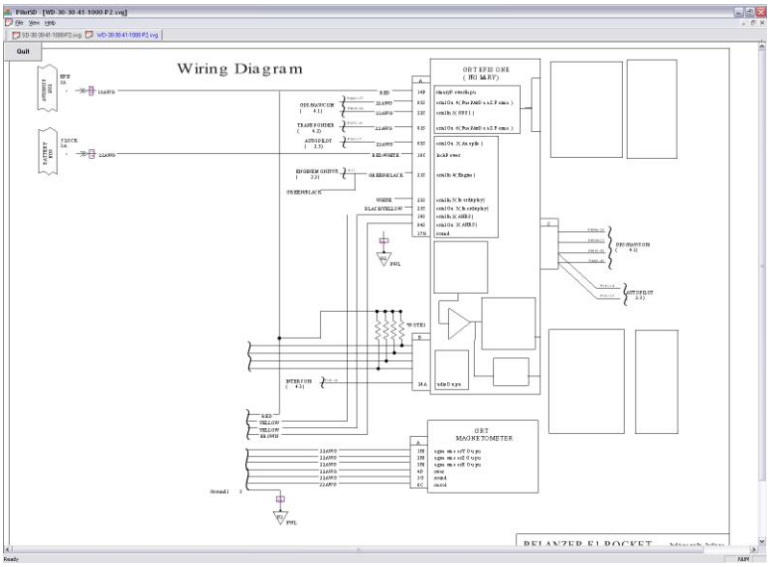
4) Move to the related wiring diagram

If the current active schematic diagram is linked with a specific wiring diagram, a sub-menu, "Link," is shown in the context menu when you right click the mouse on any place in a document. Choose the title of a wiring diagram shown in the context menu, and then the related wiring diagram is opened and displayed.

1. Right click the mouse on any position of the current diagram, and select "Link" and select "WD-30-41-1000-P2" on the context menu to open the related wiring diagram.



<Context menu for moving to the related wiring diagram>

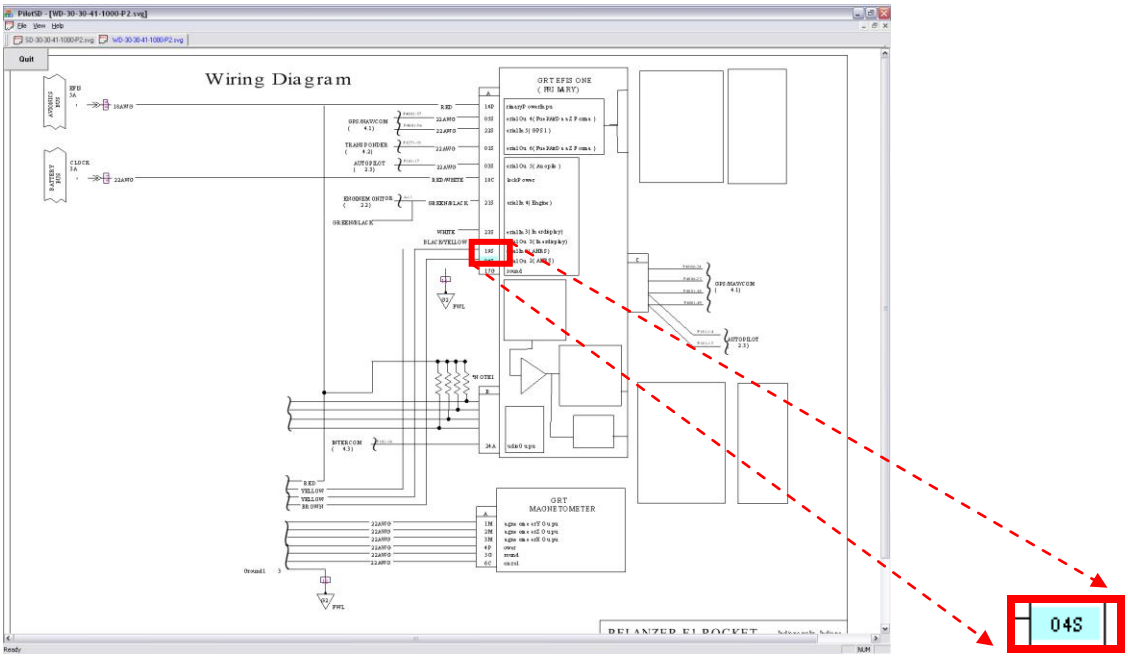


<Wiring diagram opened>

5) Find a pin number

Each component can have several pin numbers. These pin numbers will not be highlighted when you move a mouse. However, you can double click on a pin number to select it, then the pin number will be highlighted in cyan.

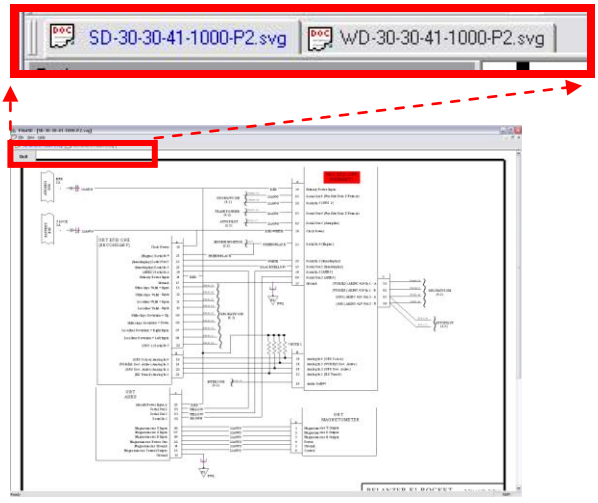
1. Find the pin number on the “GRTEFIS ONE (PRIMARY)” which connects to BROWN pin of another component, and double click on the pin number.



6) Return back to the schematic diagram

When a diagram is opened, a tab interface is also displayed on the top-left of the diagram with the file name as a title. If multiple diagrams are opened, new tab will be displayed next to the previous one. You can select one of the tabs to change the current active diagram.

1. Return back to the initial schematic diagram by selecting the tab for the "SD-30-30-41-1000-P2"

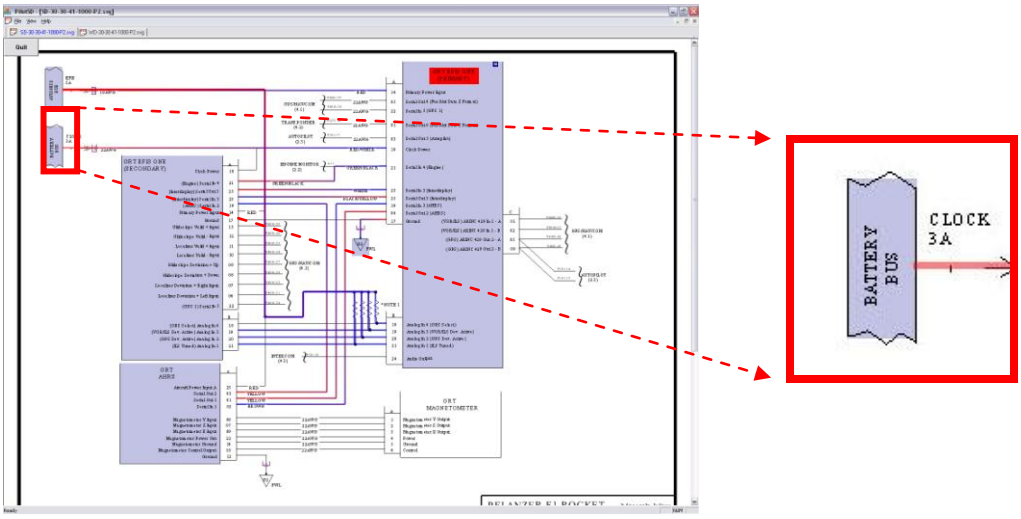


<Tabbed interface>

7) Search for the power source

When a component has been focused, all links and components on the backward path from the component are highlighted. You can use this to find the power sources.

1. Find the power source of “GRTEFIS ONE (PRIMARY)”.

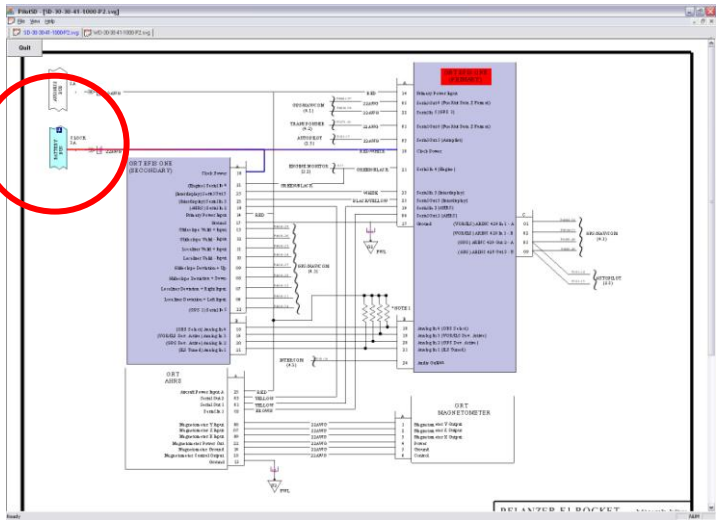


<Highlight the path from the focused component to the power source>

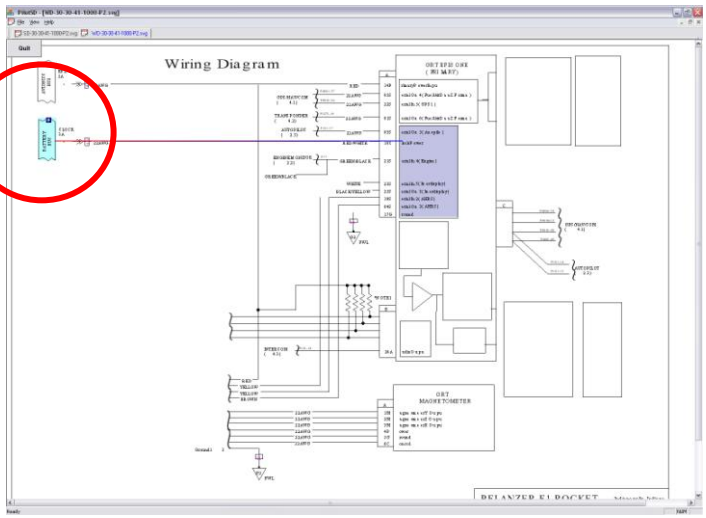
8) Maintain contextual information between related diagrams

Contextual information, such as highlighting a component is maintained between related diagrams. Therefore, when multiple diagrams are opened, you can understand the relationship between them by the contextual information maintained.

1. You have two diagrams opened now.
2. On the SD-30-30-41-1000-P2 diagram,
   Double click the power source of “GRTEFIS ONE (PRIMARY)”.
3. Check that the highlighting of power source is maintained in the WD-30-30-41-1000-P2 as shown in the figures below.



(a) SD-30-30-41-1000-P2

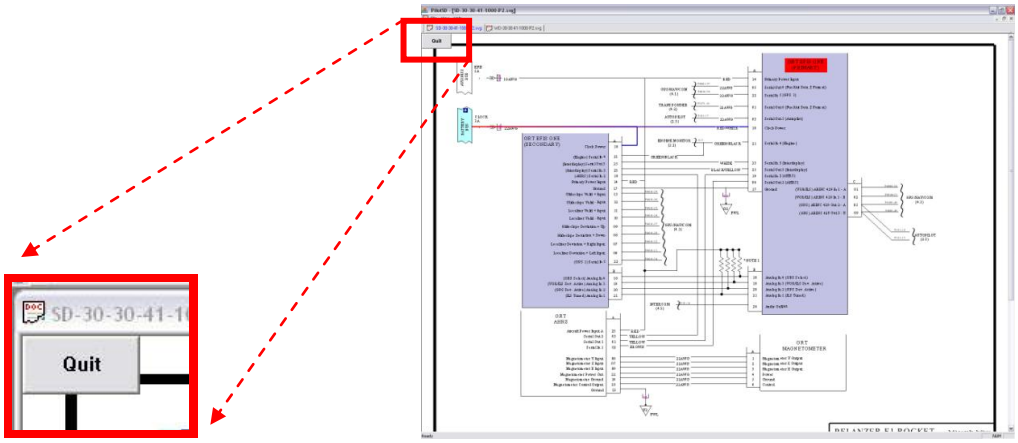


(b) WD-30-30-41-1000-P2

<Context information maintained in a related diagram>

9) Exit the training

1. To exit the training, select the “Quit” button on the left top corner.



<Quit the training>

Evaluation Questions (Task 1Training)

Once you feel you understand how to use the system, you will be given evaluation questions. You must receive 100 percent on the evaluation to continue to the experiment.

Instructions for Task 1 (Task 1A-2)

Subtask 1

For this subtask, you start with a schematic diagram containing a component ("Window Left 4") highlighted in red.

When you double click a component to mark the answer, a message box stating "Is this your answer?" will appear. Click the "OK" button to record your answer, or click "Cancel."

Instruction
• Find the 115V circuit breaker power source that is the power for the component, "Window Left 4", and double click on the power source component.

Instructions for Task 1 (Task 1B-4)

Subtask 2

For this subtask, you start with a schematic diagram containing a component ("L9 L Side Window") highlighted in cyan.

When you double click a pin number to mark the answer, a message box stating "Is this your answer?" will appear. Click the "OK" button to record your answer, or click "Cancel."

Step #	**Instruction**
1	• Open and move to the related wiring diagram, "WD-30-41-12-P1_2".
2	In the opened wiring diagram: • Find "L9 L Side Window Power On Light" • Double click the pin number on the "E3-3 Electrical Shelf" connecting to the "L9 L Side Window Power On Light".

Instructions for Task 1 (Task 1B-3)

Subtask 3

For this subtask, you start with a schematic diagram containing a component ("S3 Left Side Window SW") highlighted in cyan.

When you double click a pin number to mark the answer, a message box stating "Is this your answer?" will appear. Click the "OK" button to record your answer, or click "Cancel."

Step #	**Instruction**
1	• Open and move to the related wiring diagram, "WD-30-41-12-P1_2".
2	In the opened wiring diagram: • Find "S3 Left Side Window SW" • Double click the pin number on the "P5-9 Window and PI Tot Heat Module" connecting to pin "1C" of the "S3 Left Side Window SW".

Instructions for Task 1 (Task 1B-6)

Subtask 4

For this subtask, you start with a schematic diagram containing a component ("P6-12 Circuit Breaker Panel") highlighted in cyan.

When you double click a pin number to mark the answer, a message box stating "Is this your answer?" will appear. Click the "OK" button to record your answer, or click "Cancel."

Step #	**Instruction**
1	• Open and move to the related wiring diagram, "WD-30-41-12-P1_1".
2	In the opened wiring diagram: • Find "P6-12 Generator-2 and External Power" • Double click the pin number on the "M322 Window Heat Control Module" connecting to the "P6-12 Generator-2 and External Power".

Instructions for Task 1 (Task 1B-2)

Subtask 5

For this subtask, you start with a schematic diagram containing a component ("M322 Window Heat Control Module") highlighted in cyan.

When you double click a pin number to mark the answer, a message box stating "Is this your answer?" will appear. Click the "OK" button to record your answer, or click "Cancel."

Step #	**Instruction**
1	• Open and move to the related wiring diagram, "WD-30-41-12-P1_1".
2	In the opened wiring diagram: • Find the "M322 Window Heat Control Module" • Find the pin number on the "M322 Window Heat Control Module" which connects to pin 18 of the "E3-3 Electrical Shelf" component.

Instructions for Task 1 (Task 1A-1)

Subtask 6

For this subtask, you start with a schematic diagram containing a component ("Proportional Control") highlighted in red.

When you double click a component to mark the answer, a message box stating "Is this your answer?" will appear. Click the "OK" button to record your answer, or click "Cancel."

Instruction
• Find the 115V circuit breaker power source that is the power for the component, "Proportional Control", and double click on the power source component.

Instructions for Task 1 (Task 1B-1)

Subtask 7

For this subtask, you start with a schematic diagram containing a component ("T271 Terminal strip") highlighted in cyan.

When you double click a pin number to mark the answer, a message box stating "Is this your answer?" will appear. Click the "OK" button to record your answer, or click "Cancel."

Step #	**Instruction**
1	• Open and move to the related wiring diagram, "WD-30-41-12-P1_1".
2	In the opened wiring diagram: • Find "E3-3 Electrical shelf" • Find the pin number on the "E3-3 Electrical shelf" for the internal "T271 Terminal strip" component, and double click on the pin number.

Instructions for Task 1 (Task 1A-3)

Subtask 8

For this subtask, you start with a schematic diagram containing a component ("A13 Window left side 2") highlighted in red.

When you double click a component to mark the answer, a message box stating "Is this your answer?" will appear. Click the "OK" button to record your answer, or click "Cancel."

Instruction
• Find the 115V circuit breaker power source that is the power for the component, "A13 Window left side 2", and double click on the power source component.

Instructions for Task 1 (Task 1B-5)

Subtask 9

For this subtask, you start with a schematic diagram containing a component ("L7 L FWD Window On") highlighted in cyan.

When you double click a pin number to mark the answer, a message box stating "Is this your answer?" will appear. Click the "OK" button to record your answer, or click "Cancel."

Step #	**Instruction**
1	• Open and move to the related wiring diagram, "WD-30-41-11-P1_2".
2	In the opened wiring diagram: • Find "L7 L. Front Window Power On LT" • Double click the pin number on the "E3-3 Electrical Shelf" connecting to the "L7 L. Front Window Power On LT".

Appendix B-3-b. Instruction sheet for Task 1 *(Group B)*

Evaluation Study: Novel Presentation Methods for Technical Data

Hello, and welcome to this evaluation study. Please refer to this document during your experiment, as it will provide you with all necessary instructions for completing your task. Whenever you are not sure about the task or if you do not feel comfortable at any time during the experiment, please TELL us.

Your task

During this experiment you will be asked to find different components in various wiring diagrams per the written instructions. The system will log the timing, mouse clicks, and movement information. The goal is to find the component as quickly as possible while maintaining 100 percent accuracy.

How to use SDViz?

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<Training Instructions>
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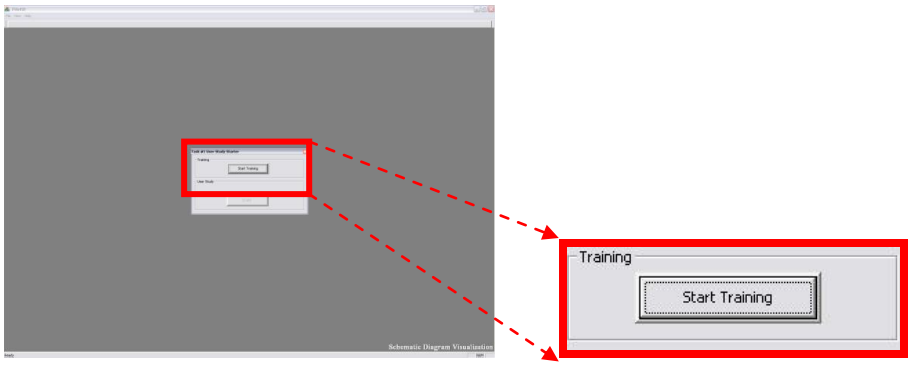
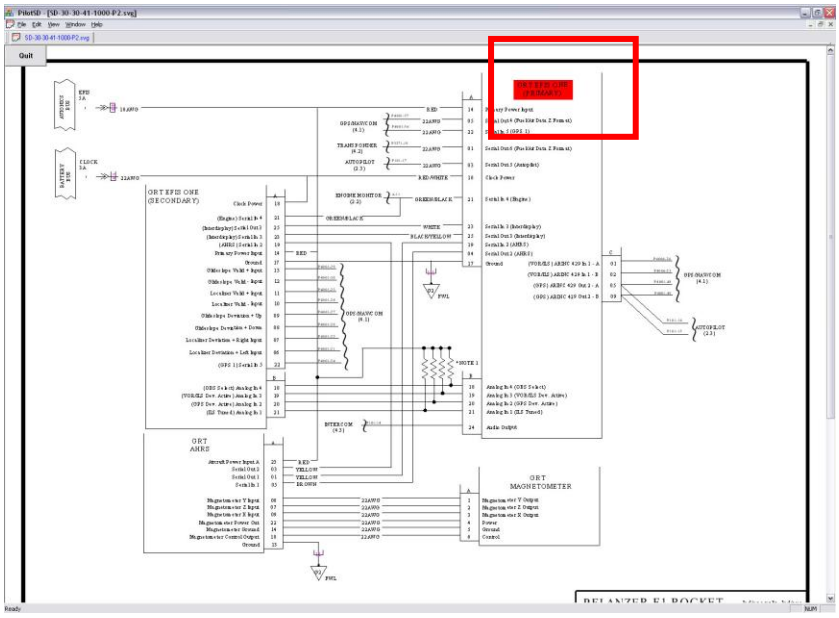


<Initial Screenshot>

You will start our training using the schematic diagram containing the component (“GRTEFIS ONE [PRIMARY]”) highlighted in red.

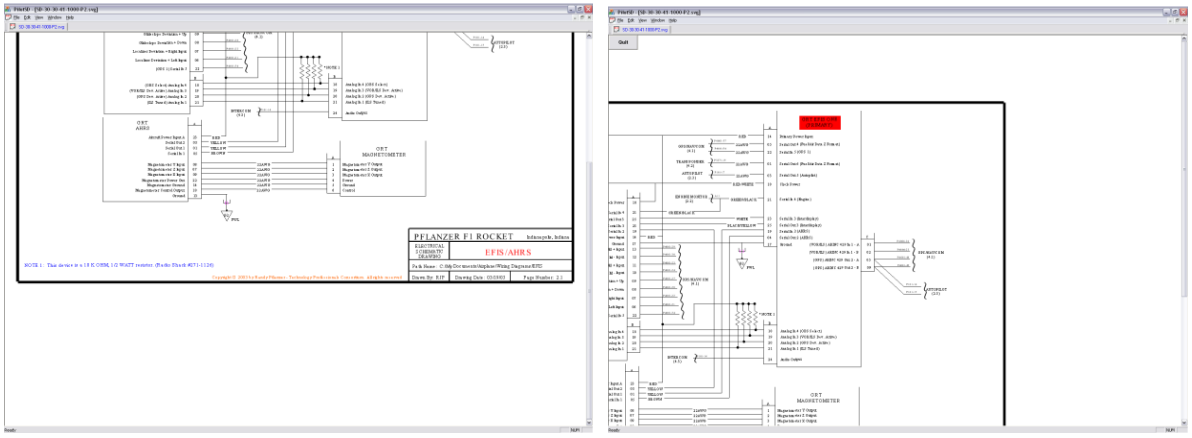


<Initial highlighting for training>

1) Scrolling / panning a diagram

You can scroll or pan a diagram to transform the view. To scroll a diagram, use the vertical scroll bar on the right side of the SDViz. To pan a diagram, you can left click and hold the mouse button dragging a diagram.

1. Scroll or pan a diagram to make the view like figures below.

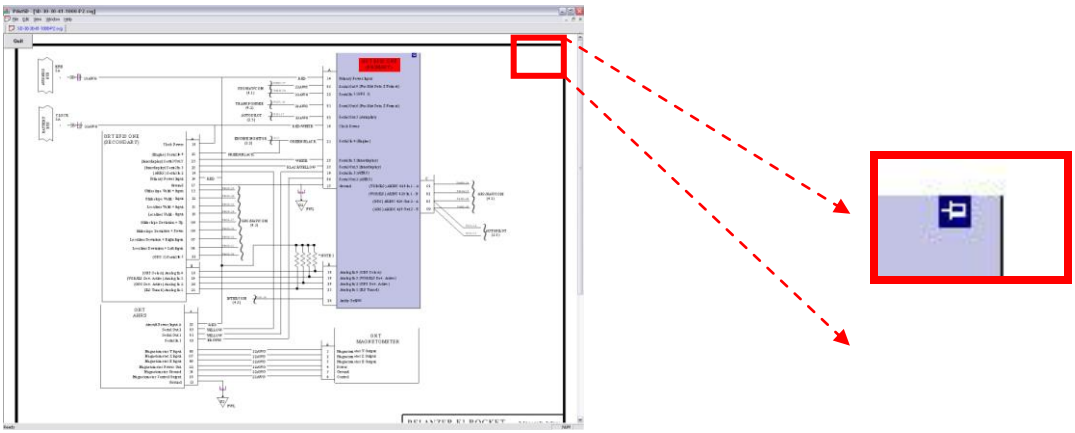


<View transform by scrolling (left) and panning (right) a diagram>

2) Highlight a component

Place the mouse cursor on any component in the diagram (you don't need to click any mouse buttons). The component is focused with a pin icon ( ) in its upper right corner and highlighted in light purple. This highlighting will be maintained while moving and holding the left mouse button.

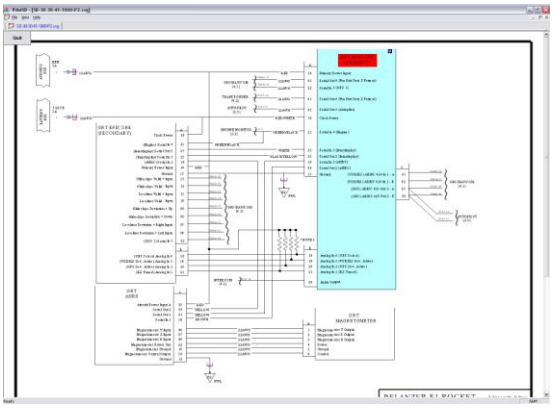
1. Move the mouse cursor to the component "GRTEFIS ONE (PRIMARY)", and see the component highlighted.
2. Hold the left mouse button on the component "GRTEFIS ONE (PRIMARY)", and move the mouse.



<Highlight a component>

During the training and user test, you will also use the highlighting by double click to answer each subtask, and you should see the component highlighted in cyan.

1. Double click the "GRTEFIS ONE (PRIMARY)", and confirm that the highlight color of the component is changed.
2. Double click the mouse button on any position of the background of the diagram to release it.

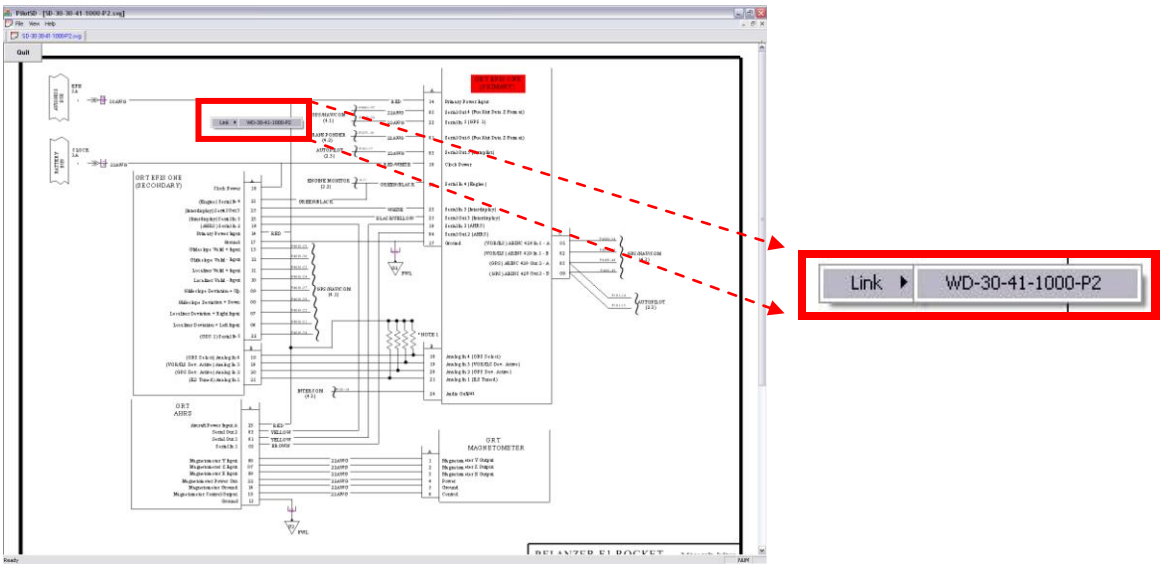


<Double click a component>

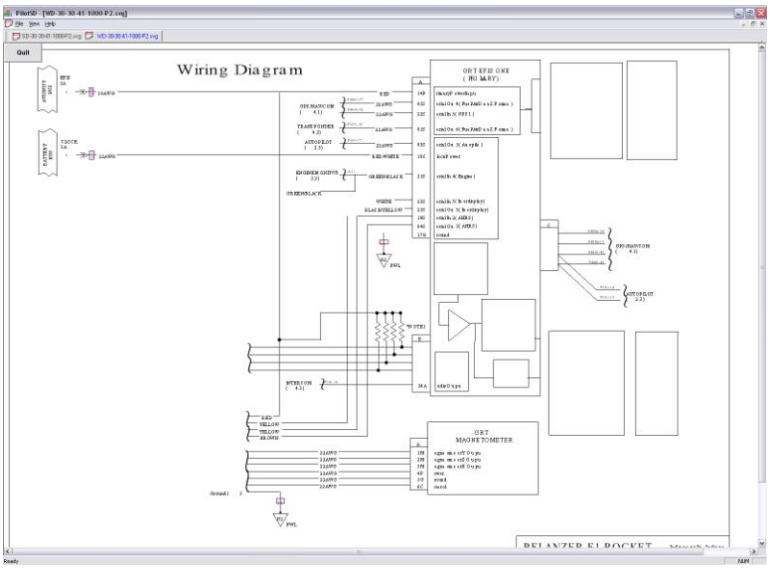
3) Move to the related wiring diagram

If the current active schematic diagram is linked with a specific wiring diagram, a sub-menu, “Link,” is shown in the context menu when you right click the mouse on any place in a document. Choose the title of a wiring diagram shown in the context menu, and then the related wiring diagram is opened and displayed.

1. Right click the mouse on any position of the current diagram, and select “Link” and select “WD-30-41-1000-P2” on the context menu to open the related wiring diagram.



<Context menu for moving to the related wiring diagram>

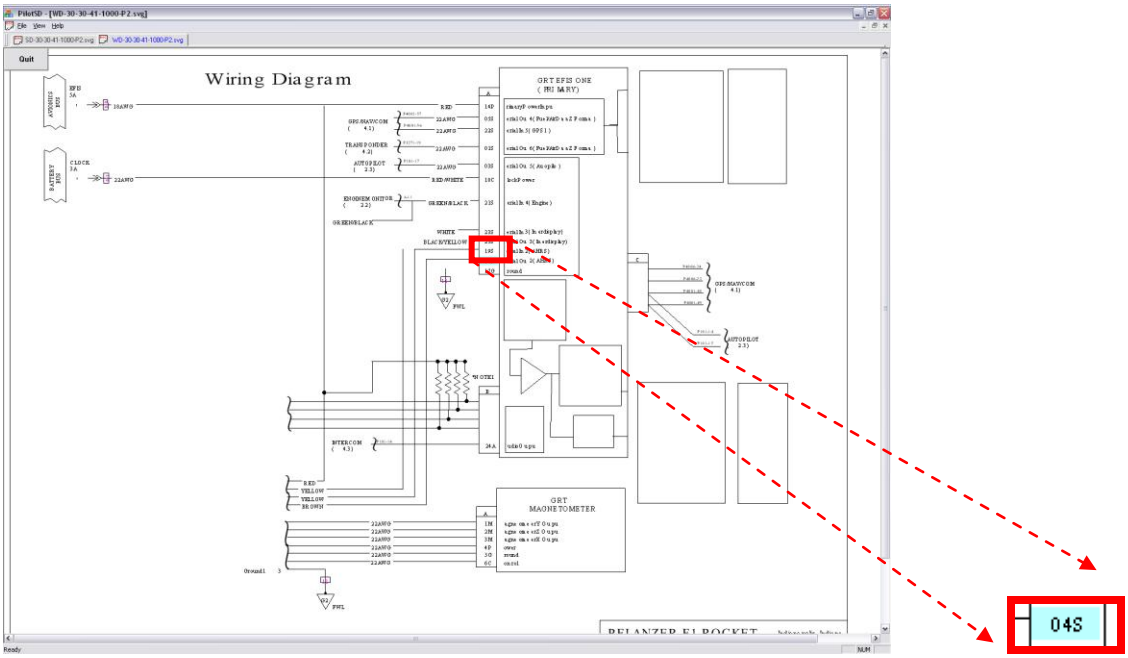


<Wiring diagram opened>

4) Find a pin number

Each component can have several pin numbers. These pin numbers will not be highlighted when you move a mouse. However, you can double click on a pin number to select it, then the pin number will be highlighted in cyan.

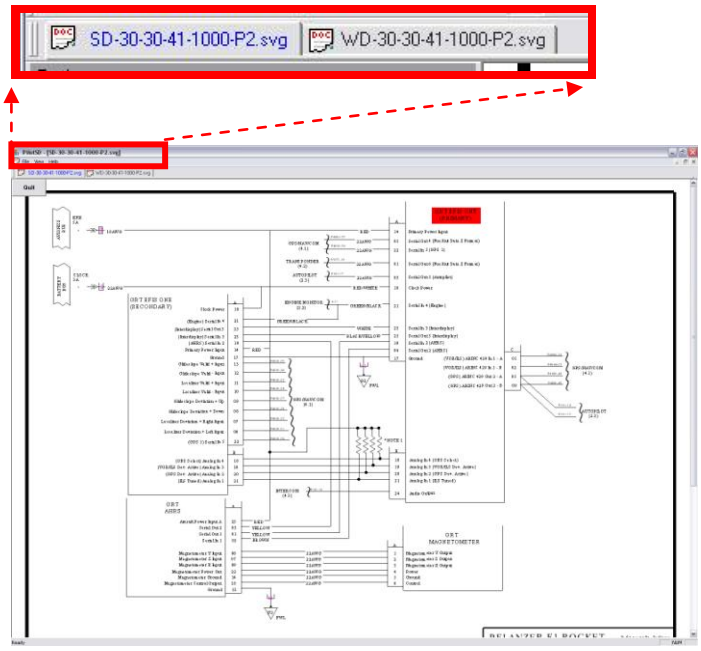
1. Find the pin number on the “GRTEFIS ONE (PRIMARY)” which connects to BROWN pin of another component, and double click on the pin number.



5) Return back to the schematic diagram

When a diagram is opened, a tab interface is also displayed on the top-left of the diagram with the file name as a title. If multiple diagrams are opened, a new tab will be displayed next to the previous one. You can select one of the tabs to change the current active diagram.

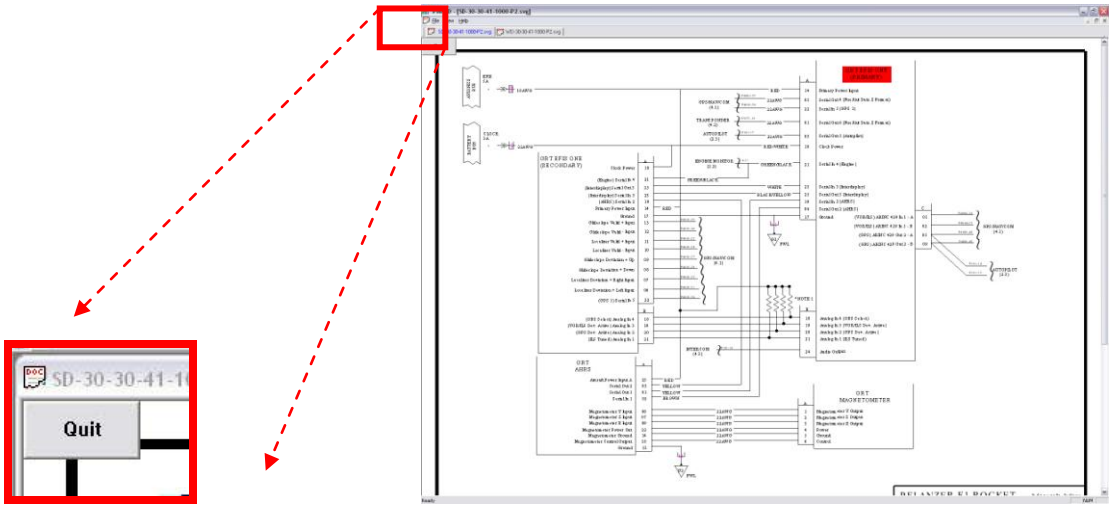
1. Return back to the initial schematic diagram by selecting the tab for the "SD-30-30-41-1000-P2"



<Tabbed interface>

6) Exit the training

1. To exit the training, select the “Quit” button on the left top corner.



<Quit the training>

Evaluation Questions (Task 1 Training)

Once you feel you understand how to use the system, you will be given evaluation questions. You must receive 100 percent on the evaluation to continue to the experiment.

Appendix B-4-a. Post-task Questionnaire for Task 1 *(Group A)*

Evaluation Study: Novel Presentation Methods for Technical Data

The following questions will be used to collect information for our evaluation study. Please mark your response or write down the answer.

Q1. Mark one of the numbers to describe your overall impression of **how easy it is to use the user interface of SDViz**.

(1: Very easy, 2: Easy, 3: No opinion, 4: Not easy, 5: Difficult, or Not Applicable [N/A])

- Highlighting a component [1 2 3 4 5 N/A]
- Moving to the related wiring diagram [1 2 3 4 5 N/A]
- Using the tab interface [1 2 3 4 5 N/A]
- Highlighting the path to the power source [1 2 3 4 5 N/A]

Comments:

(Please give your comments.)

Q2. Mark one of the numbers to describe your opinion of **which features are useful**.

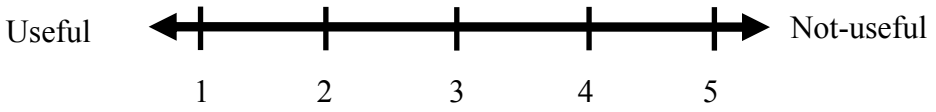
(1: Very useful, 2: Useful, 3: No opinion, 4: Not bad, 5: Not useful, or Not Applicable [N/A])

- Highlight components [1 2 3 4 5 N/A]
- Highlight links (connections) [1 2 3 4 5 N/A]
- Move to the related diagram by using Link menu [1 2 3 4 5 N/A]
- Move to another diagram by using a tab interface [1 2 3 4 5 N/A]
- Find the power source by highlighting the path [1 2 3 4 5 N/A]
- Maintain the context information between related diagrams [1 2 3 4 5 N/A]

Comments:

(Please give your comments.)

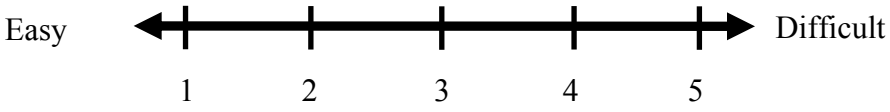
Q3. You tested finding a specific component (power source) by highlighting the path to the power source. Mark one of the following to describe your opinion of **how useful it was to use the function in finding the power source.**



Comments:

(Please give your comments.)

Q4. Mark one of the following to describe your overall impression of **how easy it was to find the desired information in related diagrams by maintaining the context between related diagrams when you moved to the related diagrams**.



Comments:

(Please give your comments.)

Thank you for your time.

Appendix B-4-b. Post-task Questionnaire for Task 1 *(Group B)*

Evaluation Study: Novel Presentation Methods for Technical Data

The following questions will be used to collect information for your evaluation study. Please mark your response or write down the answer.

Q1. Mark one of the numbers to describe your overall impression of **how easy it is to use the user interface of SDViz**.

(1: Very easy, 2: Easy, 3: No opinion, 4: Not easy, 5: Difficult, or Not Applicable [N/A])

- Highlighting a component [1 2 3 4 5 N/A]
- Moving to the related wiring diagram [1 2 3 4 5 N/A]
- Using a tab interface [1 2 3 4 5 N/A]

Comments:

(Please give your comments.)

Q2. Mark one of the numbers to describe your opinion of **which features are useful**.

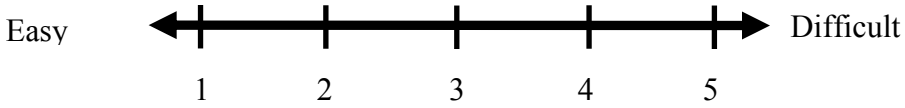
(1: Very useful, 2: Useful, 3: No opinion, 4: Not bad, 5: Not useful, or Not Applicable [N/A])

- Highlight components [1 2 3 4 5 N/A]
- Move to the related diagram by using Link menu [1 2 3 4 5 N/A]
- Move to another diagram by using a tab interface [1 2 3 4 5 N/A]

Comments:

(Please give your comments.)

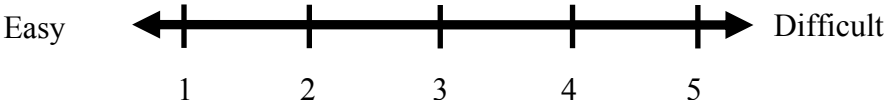
Q3. Mark one of the following to describe your overall impression of **how easy it was to find the power source from any component**.



Comments:

(Please give your comments.)

Q4. Mark one of the following to describe your overall impression of **how easy it was to find desired information in related diagrams when you moved to the related diagrams**.



Comments:

(Please give your comments.)

Thank you for your time.

Appendix B-2-a revised. Evaluation questions (Task 1B Training) ***(Group A, B)***

Evaluation Study: Novel Presentation Methods for Technical Data

The following questions will test your training status. Please mark or write down your answer for the following questions.

Q1. Using our system, what actions must be performed in order to focus/highlight a component?

1) Left click on a component ( )
2) Right click on a component ( )
3) Middle button click on a component ( )
4) Mouse over a component ( )

Q2. What actions must be performed in order to move to the related wiring diagram?

1) Left click the mouse button and select “Link” ( )
2) Right click the mouse button and select “Link” ( )
3) Double click on any position ( )
4) Mouse over a component and select “Link” ( )

Q3. What information is maintained between related diagrams?

Appendix B-2-b revised. Evaluation questions (Task 1B Training) ***(Group C, D)***

Evaluation Study: Novel Presentation Methods for Technical Data

The following questions will test your training status. Please mark or write down your answer for the following questions.

Q1. What actions must be performed in order to move to the related wiring diagram?

1) Left click the mouse button and select “Link” ( )
2) Right click the mouse button and select “Link” ( )
3) Double click on any position ( )
4) Mouse over a component and select “Link” ( )

Q2. What information is maintained between related diagrams? (Write “Nothing” if there is no information maintained between them.)

Appendix B-2-c revised. Answers for Evaluation questions (Task 1 Training)

Evaluation Study: Novel Presentation Methods for Technical Data

Q1, Q2, and Q4 are for Groups A and B. Q3 and Q4 are for Groups C and D.

Q1. Using our system, what actions must be performed in order to focus/highlight a component?

1) Left click on a component ( )
2) Right click on a component ( )
3) Middle button click on a component ( )
4) Mouse over a component (O)

Q2. What actions must be performed in order to move to the related wiring diagram?

1) Left click the mouse button and select "Link" ( )
2) Right click the mouse button and select "Link" (O)
3) Double click on any position ( )
4) Mouse over a component and select "Link" ( )

Q3. What actions must be performed to find the power source of a component in our system? (Find two answers)

1) Left click on a component and select "Link" ( )
2) Right click on a component ( )
3) Left click on a background ( )
4) Mouse over a component (O)

Q4. What information is maintained between related diagrams?

For Group A: **Highlighting**, **Focusing**, or **Selection**

For Group B: **Highlighting**, **Focusing**, **Selection**, **Spatial** information, or **Position** of a component

For Group C: **Spatial** information, **Position** of a component

For Group D: Nothing

Appendix B-3-revised. Instruction sheet for Task 1B

Evaluation Study: Novel Presentation Methods for Technical Data

Hello, and welcome to this evaluation study. Please refer to this document during your experiment, as it will provide you with all necessary instructions for completing your task. Whenever you are not sure about the task or if you do not feel comfortable at any time during the experiment, please TELL us.

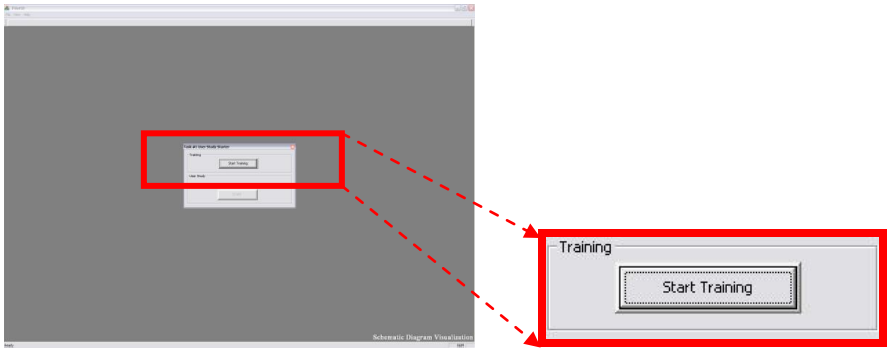
Your task

During this experiment you will be asked to find different components in various diagrams per the written instructions. The system will log the timing, mouse clicks, and movement information. The goal is to find the component as quickly as possible while maintaining 100 percent accuracy.

How to use SDViz?

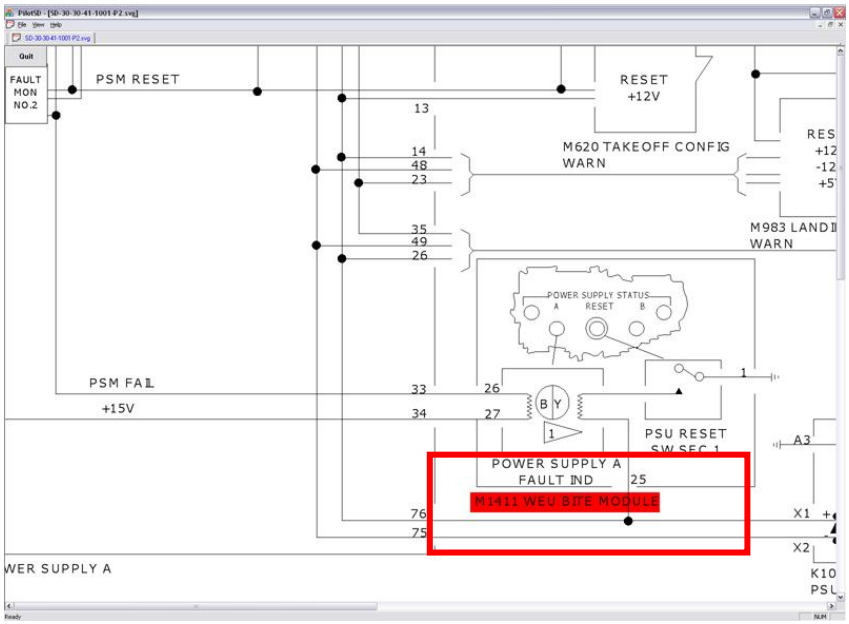
Before starting this evaluation study, you will be trained in the use of SDViz. Please read the instructions detailing the SDViz features and complete the training tasks. When you feel comfortable with the system, you will be asked to take a short quiz. You must score 100 percent on this quiz in order to continue on to the experiment. You may take as long as you feel necessary for training.

<Training Instructions>
First, click the "Start Training" button in the initial dialog, User Study Starter.



<Initial Screenshot>

You will start our training using the schematic diagram containing the component (“M1411 WEU BITE MODULE”) highlighted in red.

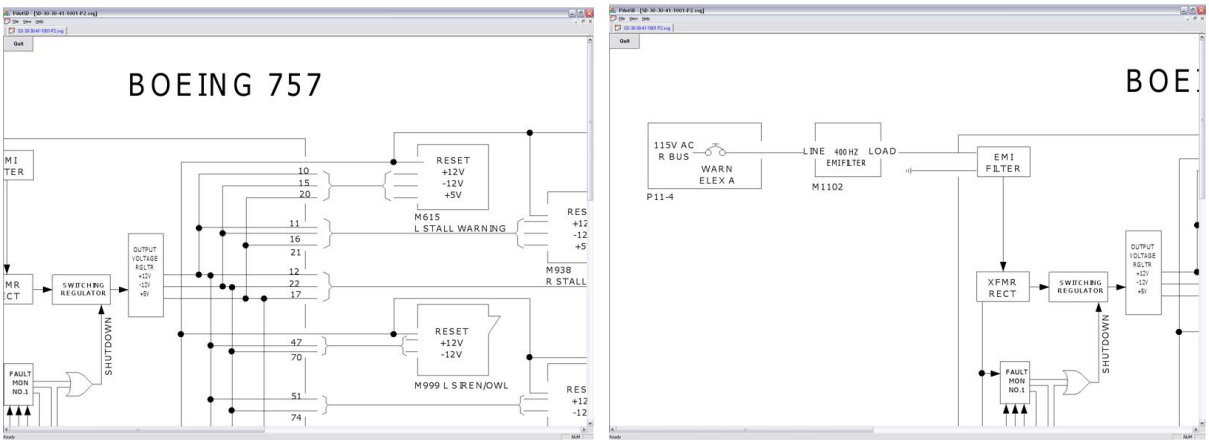


<Initial highlighting for training>

1) Scrolling/panning a diagram

You can scroll or pan a diagram to transform the view. To scroll a diagram, use the vertical/horizontal scroll bars on the right/bottom side of the SDViz. To pan a diagram, you can left click and hold the mouse button while dragging a diagram.

1. Scroll or pan a diagram to make the view like figures below.

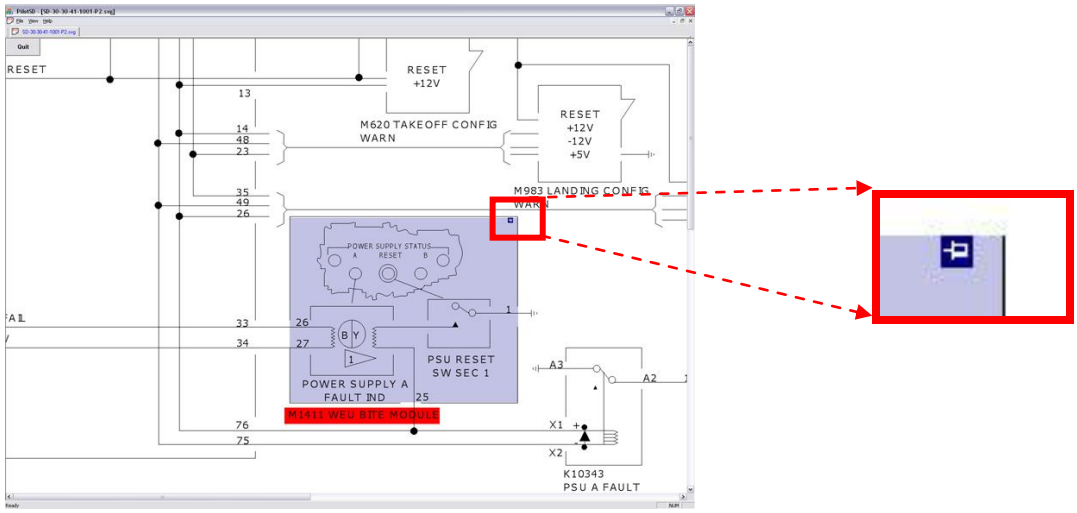


<View transformed by vertical scrolling (left) and panning (right) a diagram>

2) Highlight a component and a link

Place the mouse cursor on a component or a link in the diagram (you don't need to click any mouse buttons). The component is focused with a pin icon ( ) in its upper right corner and highlighted in light purple. The link is highlighted in color changing from red to blue making two end-components highlighted. This highlighting will be maintained while moving and holding the left mouse button.

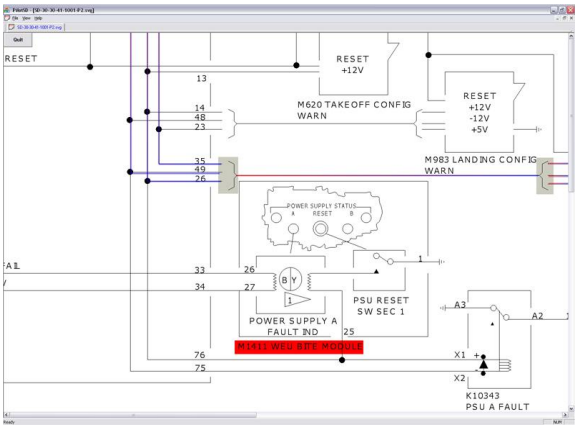
1. Move the mouse cursor to the component "M1411 WEU BITE MODULE", and see the component highlighted.
2. Hold the left mouse button on the component "M1411 WEU BITE MODULE", and move the mouse.



<Highlight a component>

(Group A, Group B)

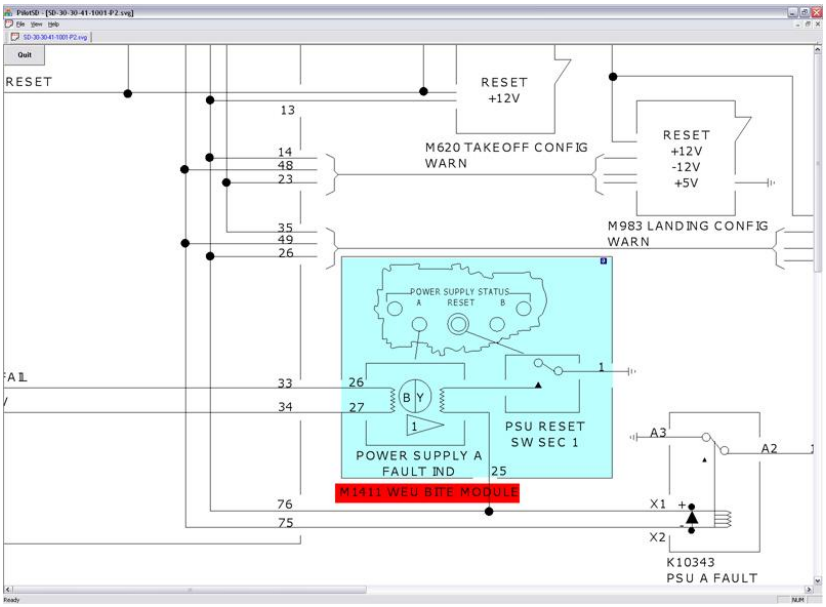
3. Move the mouse cursor to any link around "M1411 WEU BITE MODULE" like the figure below.
4. Hold the left mouse button on the link, and move the mouse.



<Highlight a link>

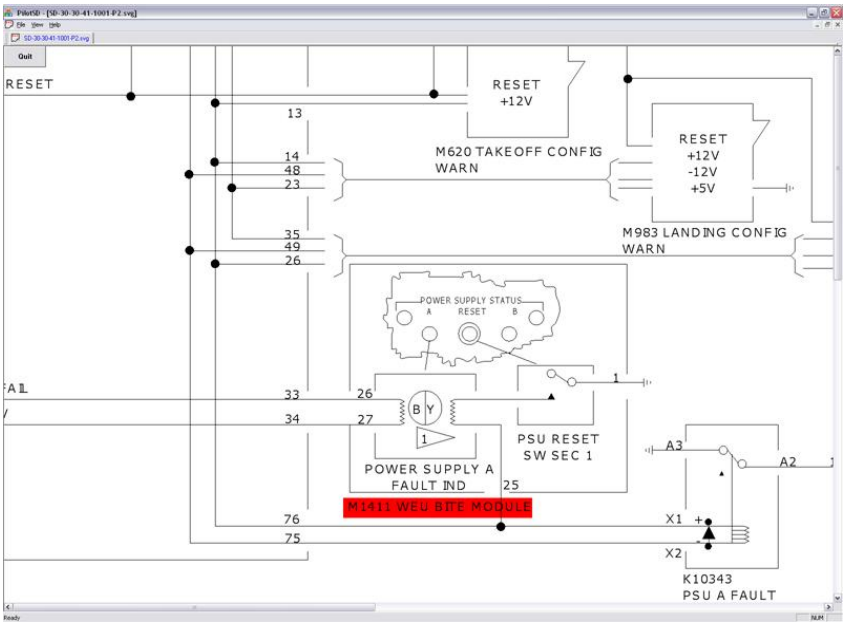
During the training and user test, you will also use the highlighting by double clicking to answer each subtask, and you should see the component highlighted in cyan. You can also double click a link but the highlighting color of a link will be the same.

1. Double click the “M1411 WEU BITE MODULE”, and confirm that the highlight color of the component is changed.



<Double click a component>

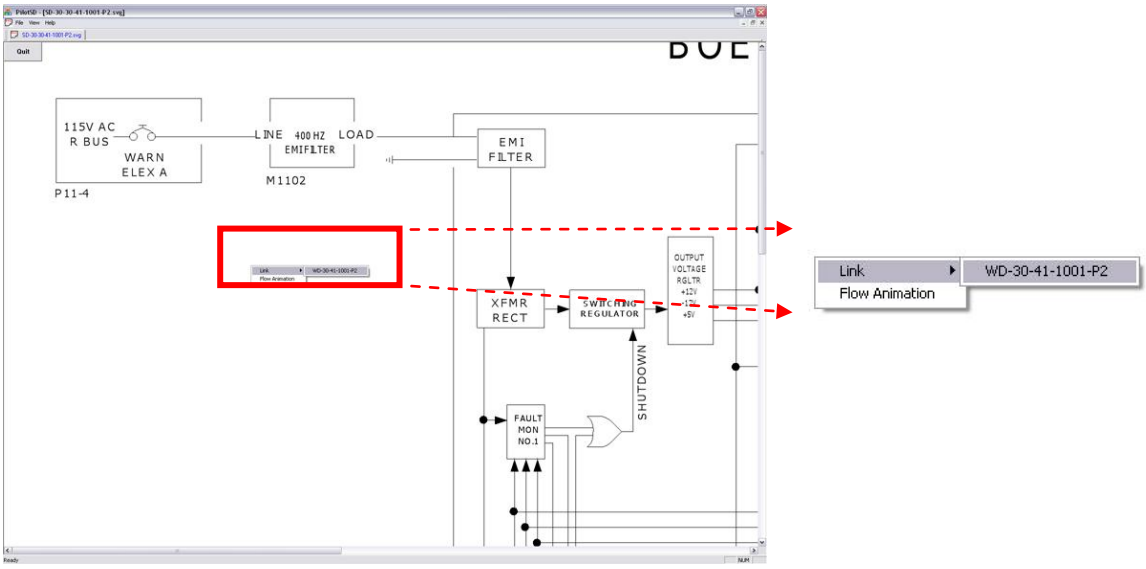
2. Double click the mouse button on any position of the background of the diagram to release it.



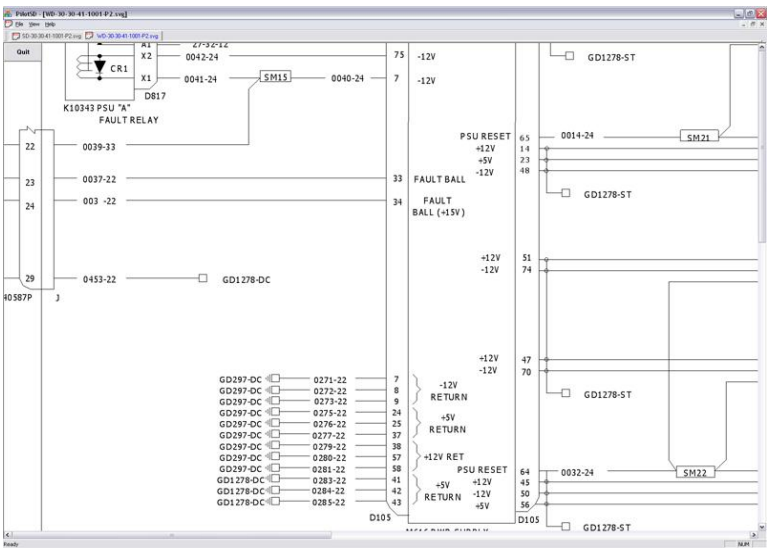
3) Move to the related wiring diagram

If the current active schematic diagram is linked with a specific wiring diagram, a sub-menu, "Link," is shown in the context menu when you right click the mouse on any place in a document. Choose the title of a wiring diagram shown in the context menu, and then the related wiring diagram is opened and displayed.

1. Right click the mouse on any position of the current diagram, and select "Link" and select "WD-30-41-1001-P2" on the context menu to open the related wiring diagram.



<Context menu for moving to the related wiring diagram>

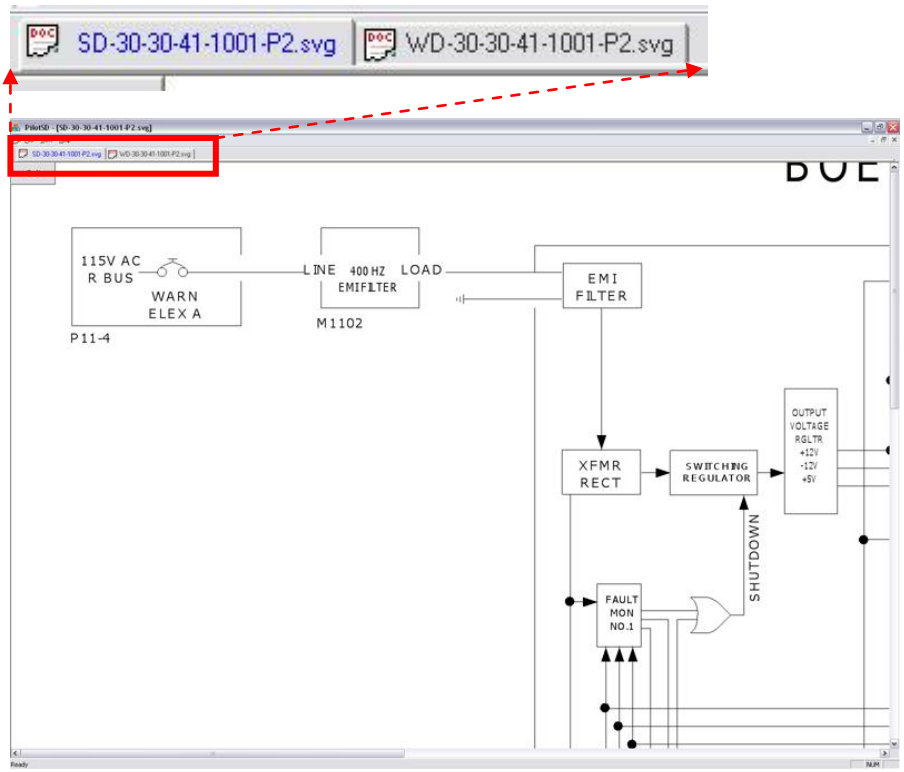


<Wiring diagram opened>

4) Return back to the schematic diagram

When a diagram is opened, a tab interface is also displayed on the top-left of the diagram with the file name as a title. If multiple diagrams are opened, a new tab will be displayed next to the previous one. You can select one of the tabs to change the current active diagram.

1. Return back to the initial schematic diagram by selecting the tab for the "SD-30-30-41-1001-P2"

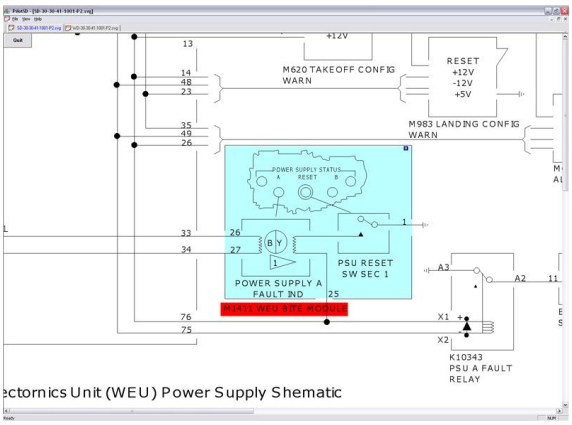


<Tabbed interface>

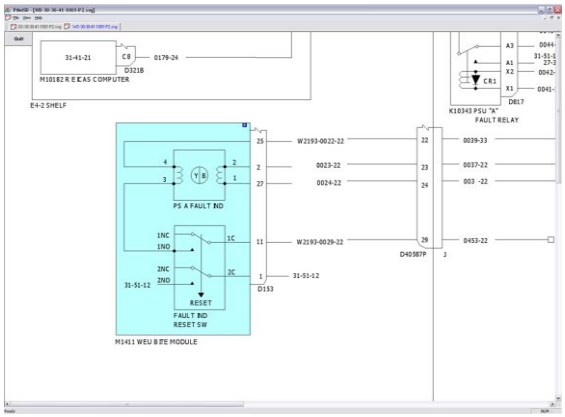
5) Maintaining contextual information between related diagrams *(Group A)*

Contextual information, such as highlighting a component is maintained between related diagrams. Therefore, when multiple diagrams are opened, you can understand the relationship between them by the contextual information maintained.

1. You have two diagrams opened now.
2. On the “SD-30-30-41-1001-P2.svg” diagram,
   Double click the “M1411 WEU BITE MODULE”.
3. Check that the highlighting of “M1411 WEU BITE MODULE" is maintained in the “WD-30-30-41-1001-P2.svg” as shown in the figures below. (You should find the highlighted component in “WD-30-30-41-1001-P2.svg” by dragging the diagram.)
4. Double click the left mouse button on any position of the background of the diagram.



(c) SD-30-30-41-1001-P2.svg



(d) WD-30-30-41-1001-P2.svg

<Contextual information maintained in the related diagrams>

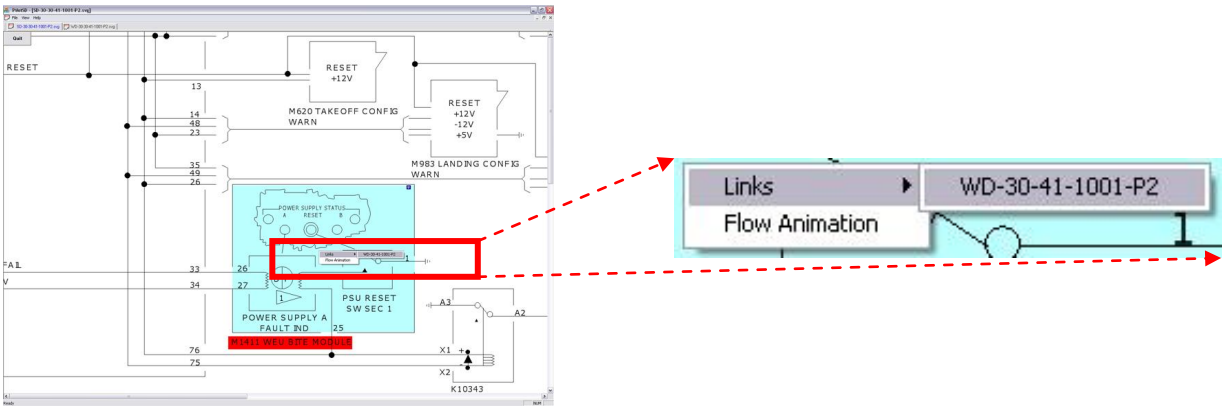
5) Maintaining contextual information between related diagrams *(Group B)*

Contextual information, such as highlighting a component as well as spatial information (e.g., position on a screen) of a component, is maintained between related diagrams. Therefore, when multiple diagrams are opened, you can understand the relationship between them by the contextual information maintained.

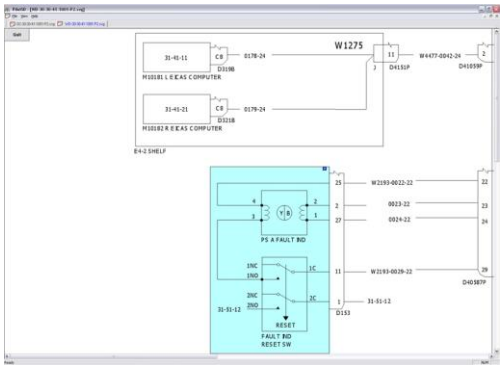
1. On the “SD-30-30-41-1001-P2.svg” diagram,
   Double click the “M1411 WEU BITE MODULE”.
2. Check that the highlighting of “M1411 WEU BITE MODULE” and spatial information (position on a screen) are maintained in the “WD-30-30-41-1001-P2.svg” by using a “Link” menu as shown in the figures below.

The spatial information maintained means that if you mouse over a component and use “Link” menu (NOT tab interface) to move to the related diagram, your mouse cursor will be positioned on the same component after moving to the related diagram.

3. Double click the left mouse button on any position of the background of the diagram.



(e) SD-30-30-41-1001-P2.svg



(f) WD-30-30-41-1001-P2.svg

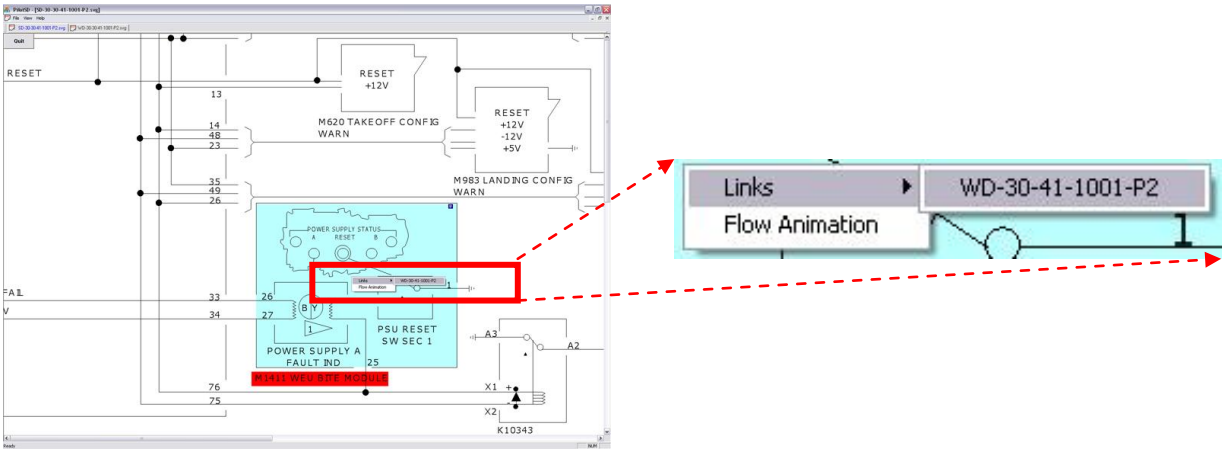
<Highlighting and spatial information maintained in the related diagrams>

5) Maintaining contextual information between related diagrams *(Group D)*

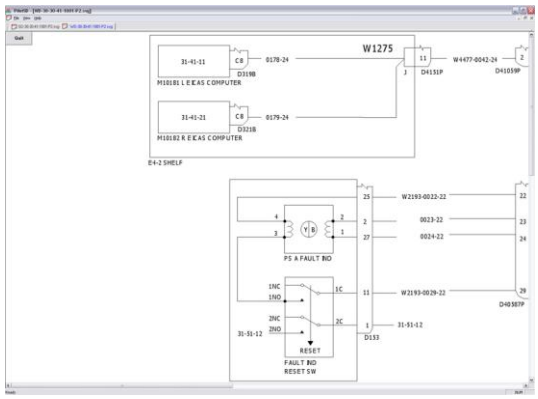
Contextual information, such as spatial information (e.g., position on a screen) of a component is maintained between related diagrams. Therefore, when multiple diagrams are opened, you can understand the relationship between them by the contextual information maintained.

1. On the "SD-30-30-41-1001-P2.svg" diagram,
   Double click the "M1411 WEU BITE MODULE".
2. Check that spatial information of "M1411 WEU BITE MODULE" (position on a screen) is maintained in the "WD-30-30-41-1001-P2.svg" by using a "Link" menu as shown in the figures below.

Spatial information maintained means that if you mouse over a component and use "Link" menu (NOT tab interface) to move to the related diagram, your mouse cursor will be positioned on the same component after moving to the related diagram.



(g) SD-30-30-41-1001-P2.svg (Change figure)

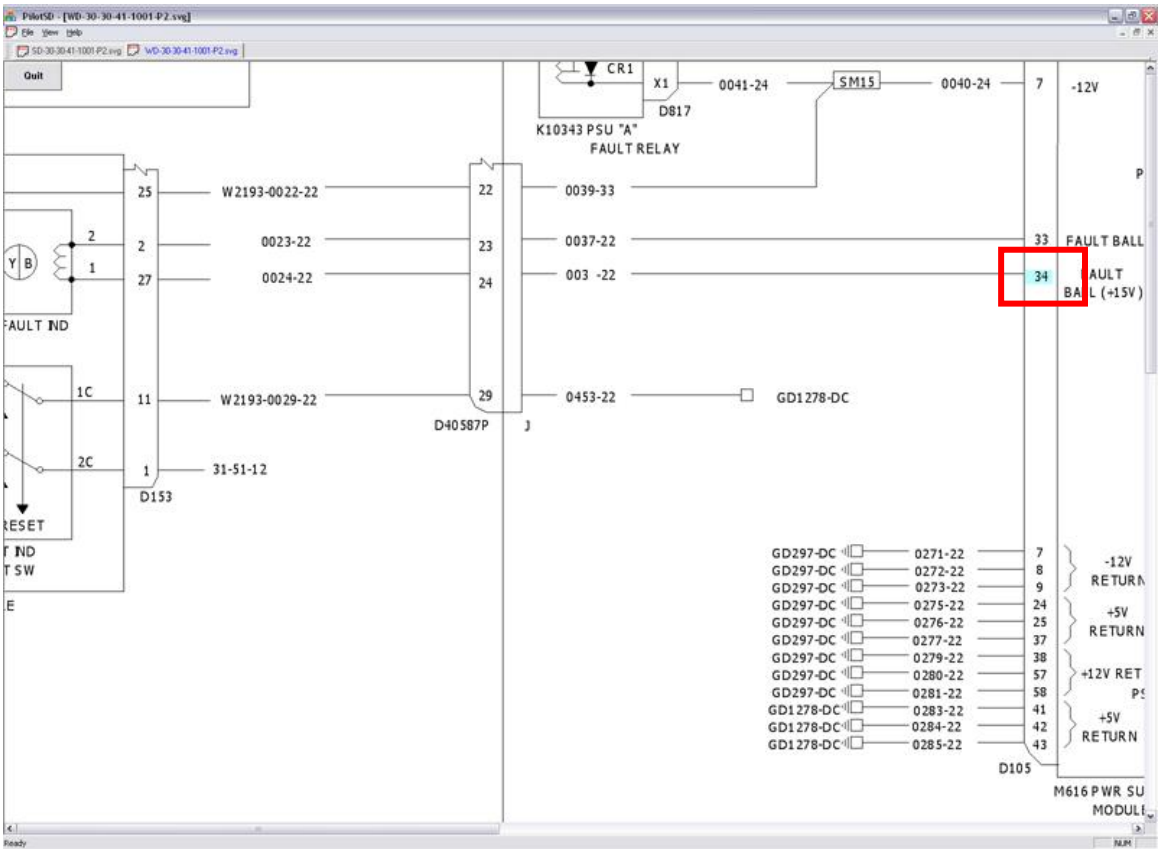


(h) WD-30-30-41-1001-P2.svg
<Spatial information maintained in the related diagrams>

6) Find a pin number

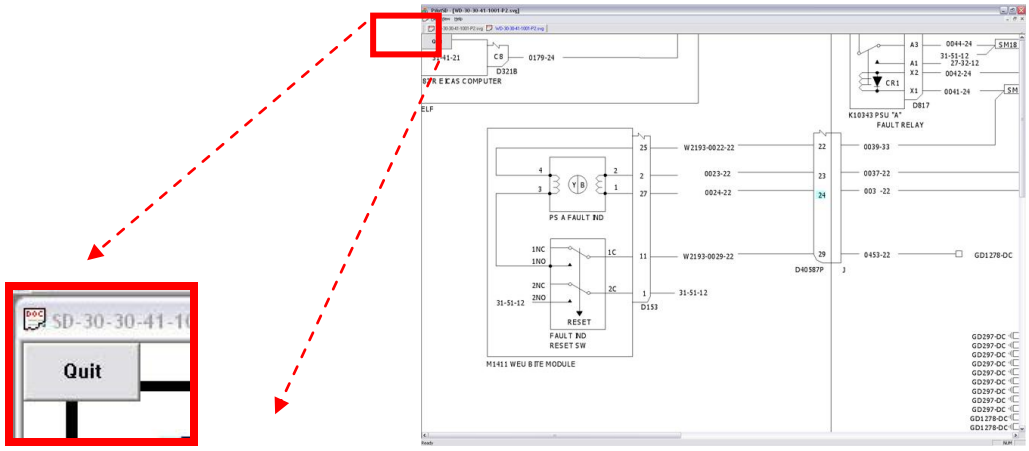
Each component can have several pin numbers. These pin numbers will not be highlighted when you move a mouse. However, you can double click on a pin number to select it, then the pin number will be highlighted in cyan.

1. In “WD-30-30-41-1001-P2.svg”, find the pin number on the “M616 PWR SUPPLY MODULE A” which connects to the pin 27 of the “M1411 WEU BITE MODULE”, and double click on the pin number.



7) Exit the training

1. To exit the training, select the “Quit” button on the left top corner.



<Quit the training>

Evaluation Questions (Task 1B Training)

Once you feel you understand how to use the system, you will be given evaluation questions. You must receive 100 percent on the evaluation to continue to the experiment.

Instructions for Task 1B (Task 1B-1)

Subtask 1

For this subtask, you start with a schematic diagram containing a component ("**L9 L Side Window**") highlighted in cyan.

When you double click a pin number to mark the answer, a message box stating "Is this your answer?" will appear. Click the "OK" button to record your answer, or click "Cancel."

If your answer is wrong, you will get the message ("You made a wrong answer. Please try it again.") and this subtask will not be finished. You have three chances to find the correct answer.

Step #	**Instruction**
1	• Open and move to the related wiring diagram, "WD-30-41-12-P1_2".
2	In the opened wiring diagram: • Find "L9 L Side Window Power On Light" • Double click the pin number on the "E3-3 Electrical Shelf" connecting to the "L9 L Side Window Power On Light".

Instructions for Task 1B (Task 1B-2)

Subtask 2

For this subtask, you start with a schematic diagram containing a component ("***L13 R Fwd Window On***") highlighted in cyan.

When you double click a pin number to mark the answer, a message box stating "Is this your answer?" will appear. Click the "OK" button to record your answer, or click "Cancel."

If your answer is wrong, you will get the message ("You made a wrong answer. Please try it again.") and this subtask will not be finished. You have three chances to find the correct answer.

Step #	**Instruction**
1	• Open and move to the related wiring diagram, "*WD-30-41-12-P1_2*".
2	In the opened wiring diagram: • Find "L13 Right Front Window Power On LT" • Double click the pin number on the "E3-3 Electrical Shelf" connecting to the "L13 Right Front Window Power On LT".

Instructions for Task 1B (Task 1B-3)

Subtask 3

For this subtask, you start with a schematic diagram containing a component ("**L10 L Side Window Overheat**") highlighted in cyan.

When you double click a pin number to mark the answer, a message box stating "Is this your answer?" will appear. Click the "OK" button to record your answer, or click "Cancel."

If your answer is wrong, you will get the message ("You made a wrong answer. Please try it again.") and this subtask will not be finished. You have three chances to find the correct answer.

Step #	**Instruction**
1	• Open and move to the related wiring diagram, "WD-30-41-11-P12A2_M2".
2	In the opened wiring diagram: • Find "L10 L. Side Window O/H LT" • Double click the pin number on the "E3-3 Electrical Shelf" connecting to the "L10 L. Side Window O/H LT".

Appendix B-4-a-revised. Post-task Questionnaire for Task 1B *(Group A, B)*

Evaluation Study: Novel Presentation Methods for Technical Data

The following questions will be used to collect information for our evaluation study. Please mark your response or write down the answer.

Q1. Mark one of the numbers to describe your overall impression of **how easy it is to use the user interface of SDViz**.

(1: Very easy, 2: Easy, 3: No opinion, 4: Not easy, 5: Difficult, or Not Applicable [N/A])

- Highlighting a component / link. [1 2 3 4 5 N/A]
- Moving to the related wiring diagram. [1 2 3 4 5 N/A]

Comments:

(Please give your comments.)

Q2. Mark one of the numbers to describe your opinion of **which features are useful**.

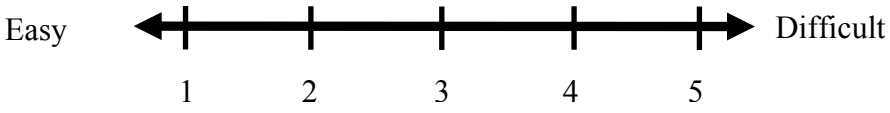
(1: Very useful, 2: Useful, 3: No opinion, 4: Not bad, 5: Not useful, or Not Applicable [N/A])

- Highlight components [1 2 3 4 5 N/A]
- Highlight links (connections) [1 2 3 4 5 N/A]
- Move to the related diagram by using Link menu [1 2 3 4 5 N/A]
- Maintain the context information between related diagrams [1 2 3 4 5 N/A]

Comments:

(Please give your comments.)

Q3. Mark one of the following to describe your overall impression of **how easy it was to find the desired information in related diagrams by using maintained contextual information between related diagrams when you moved to the related diagrams**.



Comments:

(Please give your comments.)

Q4. Give your opinion for your answer for Q3. Clearly specify how you used the maintained contextual information to find the desired information. (If you used several, give your opinion for each respectively.)

Answer:

Comments:

(Please give your comments.)

Thank you for your time.

Appendix B-4-b-revised. Post-task Questionnaire for Task 1B *(Group C)*

Evaluation Study: Novel Presentation Methods for Technical Data

The following questions will be used to collect information for our evaluation study. Please mark your response or write down the answer.

Q1. Mark one of the numbers to describe your overall impression of **how easy it is to use the user interface of SDViz**.

(1: Very easy, 2: Easy, 3: No opinion, 4: Not easy, 5: Difficult, or Not Applicable [N/A])

- Highlighting a component. [1 2 3 4 5 N/A]
- Moving to the related wiring diagram. [1 2 3 4 5 N/A]

Comments:

(Please give your comments.)

Q2. Mark one of the numbers to describe your opinion of **which features are useful**.

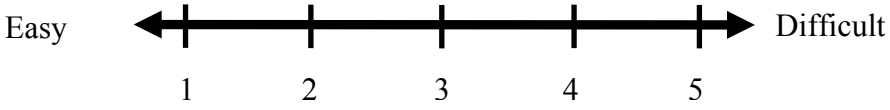
(1: Very useful, 2: Useful, 3: No opinion, 4: Not bad, 5: Not useful, or Not Applicable [N/A])

- Highlight components [1 2 3 4 5 N/A]
- Move to the related diagram by using Link menu [1 2 3 4 5 N/A]

Comments:

(Please give your comments.)

Q3. Mark one of the following to describe your overall impression of **how easy it was to find the desired information in related diagrams when you moved to the related diagrams**.



Comments:

(Please give your comments.)

Thank you for your time.

Appendix B-4-c-revised. Post-task Questionnaire for Task 1B *(Group D)*

Evaluation Study: Novel Presentation Methods for Technical Data

The following questions will be used to collect information for our evaluation study. Please mark your response or write down the answer.

Q1. Mark one of the numbers to describe your overall impression of **how easy it is to use the user interface of SDViz**.

(1: Very easy, 2: Easy, 3: No opinion, 4: Not easy, 5: Difficult, or Not Applicable [N/A])

- Highlighting a component. [1 2 3 4 5 N/A]
- Moving to the related wiring diagram. [1 2 3 4 5 N/A]

Comments:

(Please give your comments.)

Q2. Mark one of the numbers to describe your opinion of **which features are useful**.

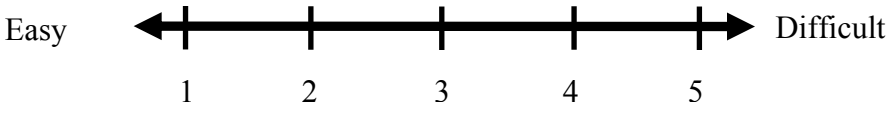
(1: Very useful, 2: Useful, 3: No opinion, 4: Not bad, 5: Not useful, or Not Applicable [N/A])

- Highlight components [1 2 3 4 5 N/A]
- Move to the related diagram by using Link menu [1 2 3 4 5 N/A]
- Maintain the context information between related diagrams [1 2 3 4 5 N/A]

Comments:

(Please give your comments.)

Q3. Mark one of the following to describe your overall impression of **how easy it was to find the desired information in related diagrams by using maintained contextual information between related diagrams when you moved to the related diagrams**.



Comments:

(Please give your comments.)

Q4. Give your opinion for your answer for Q3. Clearly specify how you used the maintained contextual information to find the desired information. (If you used several, give your opinion for each respectively.)

Answer:

Comments:

(Please give your comments.)

Thank you for your time.

Appendix C-1. Evaluation Methods for Task 2 and Task 3

1. Subjects

Subjects participating in the evaluation study for Tasks 2 and 3 should have completed an introductory Electrical Engineering (EE) course but require no aircraft knowledge. All subjects are classified into two groups: Groups A and B. Each group performs procedures in "Instructions for Tasks 2 and 3," after completing the system training.

2. Pre-interview

In order to evaluate each subject's background knowledge and skill level, each subject will answer the questions provided in the Pre-task Questionnaire.

3. Training

For Tasks 2 and 3, each subject will be trained in the use of SDViz. The small-task training will contain the following operations;

- Highlight a component to make it focused
- Use a magic lens
- Use tabbed interface to move between opened diagrams
- Highlight a link

(The following operations are only available for the SDViz that the subjects in Group A use. Subjects in Group B will skip the training for the following functions.)

- Use a rectangular fisheye lens based on the mouse movement
- Use transition-by-blending between the related diagrams
- Use flow animation to see the path between particular components

4. Pre-test

After training, subjects will answer the questions (Appendix C-2 Evaluation questions) provided in the Evaluation questions of training for Tasks 2 and 3 to determine whether or not they can perform the evaluation study.

5. Post-interview

After completing the evaluation study, subjects will complete a Post-task Questionnaire.

6. Observation Methods

For Tasks 2 and 3, two factors are recorded: time and mouse clicks.

- **Time:** This factor can be used to see how fast subjects achieve each substep and an entire task. Two types of time durations (e.g., each substep duration and total task duration) are saved in milliseconds whenever a user performs the given instruction for each substep and an entire task. For the data acquired from Group A and Group B, mean values for each substep and total task duration are calculated and compared.

- **Mouse clicks:** This factor can be used to see how fewer actions subjects utilize to achieve each substep and an entire task. Several types of mouse clicks during substep and entire task completion are saved as an integer number whenever a user clicks. Details of mouse events are explained in **Section 7. Data Collection** in Appendix B-1. For the data acquired from Group A and Group B, mean values for the number of mouse clicks during each substep and total task duration are calculated and compared.

- **User preference:** This factor can be used to evaluate the users' preference for the system usability of SDViz. The subjects will be asked to answer questions ratable on a Likert scale.

For analysis of the evaluation results, Tasks 2 and 3 are classified into two categories.

- Category 1: Group A performs Tasks 2 and 3 by using rectangular fisheye lens based on mouse movement, transition-by-blending, and flow animation.
- Category 2: Group B performs Tasks 2 and 3 by using magic lens, traditional tabbed window viewing, and static connection highlighting.

Appendix C-2-a. Evaluation questions (Tasks 2 and 3 Training) *(Group A)*

Evaluation Study: Novel Presentation Methods for Technical Data

The following questions will test your training status. Please mark or write down your answer for the following questions.

Q1. Which is true for the rectangular fisheye lens based on the mouse movement? (Two answers)

1) It occludes adjacent areas. ( )
2) It doesn't occlude adjacent areas. ( )
3) It makes adjacent areas shrink. ( )
4) It is applied to a diagram when a mouse movement is fast. ( )

Q2. Which is true for the transition-by-blending? (Two answers)

1) It maintains the position of the selected component while moving to the related diagram. ( )
2) Right arrow key is used to move to the related diagram. ( )
3) Up arrow key is used to move to the related diagram. ( )
4) When you left click a component, you can see the same component in the related diagram in the area of the selected component. ( )

Q3. Which is true for the flow animation?

1) It shows flow animation on one link from a selected component to the next component. ( )
2) It shows flow animation on all links from a selected component to an end component on the path. ( )
3) Mouse over a link to use flow animation. ( )
4) Mouse over a component to use flow animation. ( )

Appendix C-2-b. Evaluation questions (Tasks 2 and 3 Training) *(Group B)*

Evaluation Study: Novel Presentation Methods for Technical Data

The following questions will test your training status. Please mark your answer for the following questions.

Q1. Which is true for the magic lens? (Two answers)

1) It magnifies the fixed-size focus area. ( )
2) It makes adjacent areas shrink. ( )
3) It doesn't occlude adjacent areas. ( )
4) It occludes adjacent areas. ( )

Q2. Which is true for the tabbed window viewing?

1) It displays maintained spatial information between related diagrams. ( )
2) It shows all opened diagrams as tabbed window without any relationship. ( )
3) Double click on any component to view another tab window. ( )
4) Left click on a background to view another tab window. ( )

Q3. What actions must be performed in order to highlight links? (Two answers)

1) Left click on a link ( )
2) Mouse over a component ( )
3) Right click on a link ( )
4) Mouse over a link ( )

Appendix C-2-c. Answers for Evaluation questions (Tasks 2 and 3 Training)

Evaluation Study: Novel Presentation Methods for Technical Data

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<Group A>

Q1. Which is true for the rectangular fisheye lens based on the mouse movement? (Two answers)

1) It occludes adjacent areas. ( )
2) It doesn't occlude adjacent areas. (O)
3) It makes adjacent areas shrink. (O)
4) It is applied to a diagram when a mouse movement is fast. ( )

Q2. Which is true for the transition-by-blending? (Two answers)

1) It maintains the position of the selected component while moving to the related diagram. (O)
2) Right arrow key is used to move to the related diagram. ( )
3) Up arrow key is used to move to the related diagram. (O)
4) When you left click a component, you can see the same component in the related diagram in the area of the selected component. ( )

Q3. Which is true for the flow animation?

1) It shows flow animation on one link from a selected component to the next component. ( )
2) It shows flow animation on all links from a selected component to an end component on the path. (O)
3) Mouse over a link to use flow animation. ( )
4) Mouse over a component to use flow animation. ( )

<Group B>

Q1. Which is true for the magic lens? (Two answers)

1) It magnifies the fixed-size focus area. (O)
2) It makes adjacent areas shrink. ( )
3) It doesn't occlude adjacent areas. ( )
4) It occludes adjacent areas. (O)

Q2. Which is true for the tabbed window viewing?

1) It displays maintained spatial information between related diagrams. ( )
2) It shows all opened diagrams as tabbed window without any relationship. (O)
3) Double click on any component to view another tab window. ( )
4) Left click on a background to view another tab window. ( )

Q3. What actions must be performed in order to highlight links? (Two answers)

1) Left click on a link ( )
2) Mouse over a component (O)
3) Right click on a link ( )
4) Mouse over a link (O)

Appendix C-3-a. Instruction sheet for Tasks 2 and 3 *(Group A)*

Evaluation Study: Novel Presentation Methods for Technical Data

Hello, and welcome to this evaluation study. Please refer to this document during your experiment, as it will provide you with all necessary instructions for completing your task. Whenever you are not sure about the task or if you do not feel comfortable at any time during the experiment, please TELL us.

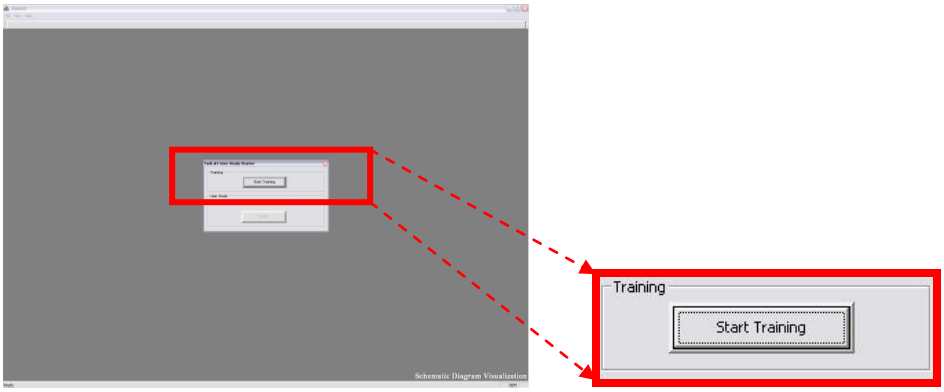
Your task

During this experiment you will be asked to find different components in various diagrams per the written instructions. The system will log the timing, mouse clicks, and movement information. The goal is to find the component as quickly as possible while maintaining 100 percent accuracy.

How to use SDViz?

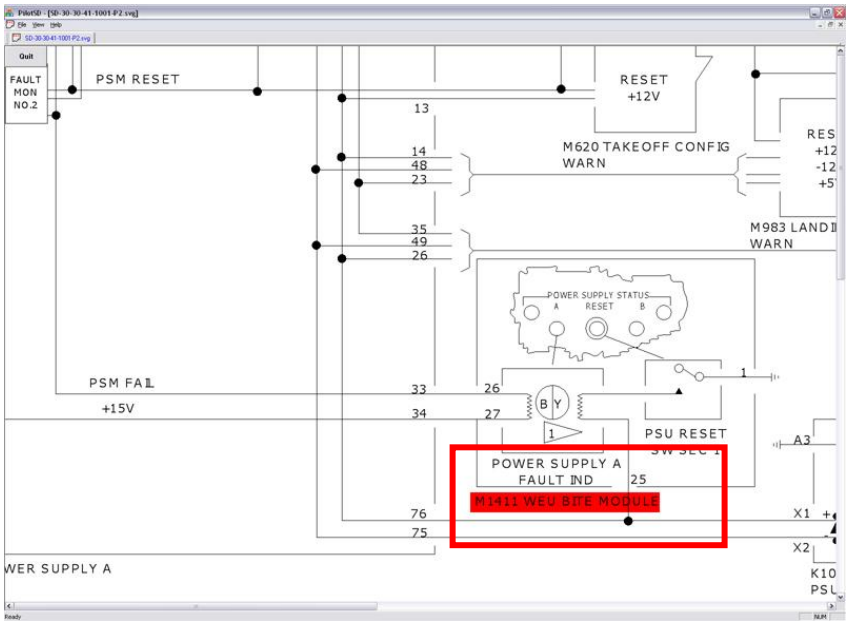
Before starting this evaluation study, you will be trained in the use of SDViz. Please read the instructions detailing the SDViz features and complete the training tasks. When you feel comfortable with the system you will be asked to take a short quiz. You must score 100 percent on this quiz in order to continue on to the experiment. You may take as long as you feel necessary for training.

<Training Instructions>
First, click the "Start Training" button in the initial dialog, User Study Starter.



<Initial Screenshot>

You will start our training using the schematic diagram containing the component (“M1411 WEU BITE MODULE”) highlighted in red.

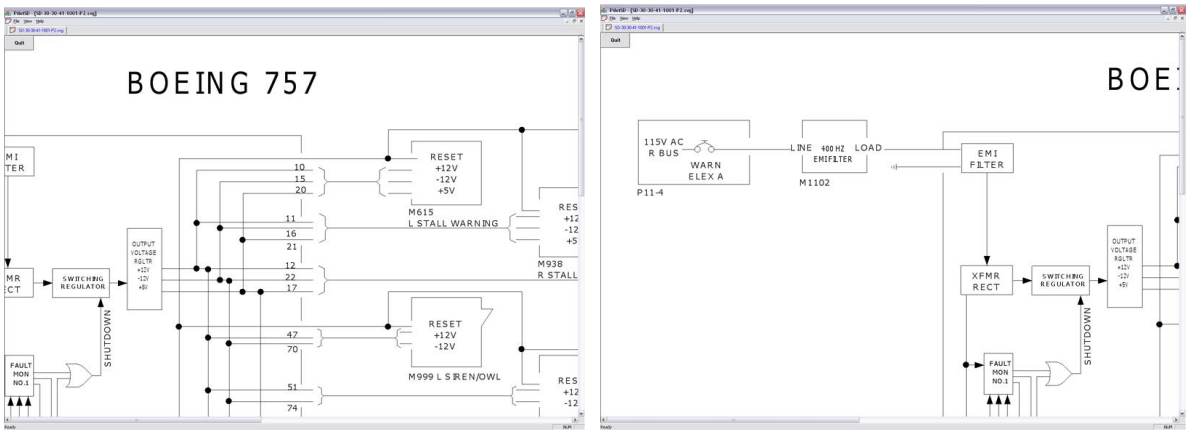


<Initial highlighting for training>

1) Scrolling/panning a diagram

You can scroll or pan a diagram to transform the view. To scroll a diagram, use the vertical/horizontal scroll bars on the right/bottom side of the SDViz. To pan a diagram, you can left click and hold the mouse button while dragging a diagram.

1. Scroll or pan a diagram to make the view like figures below.

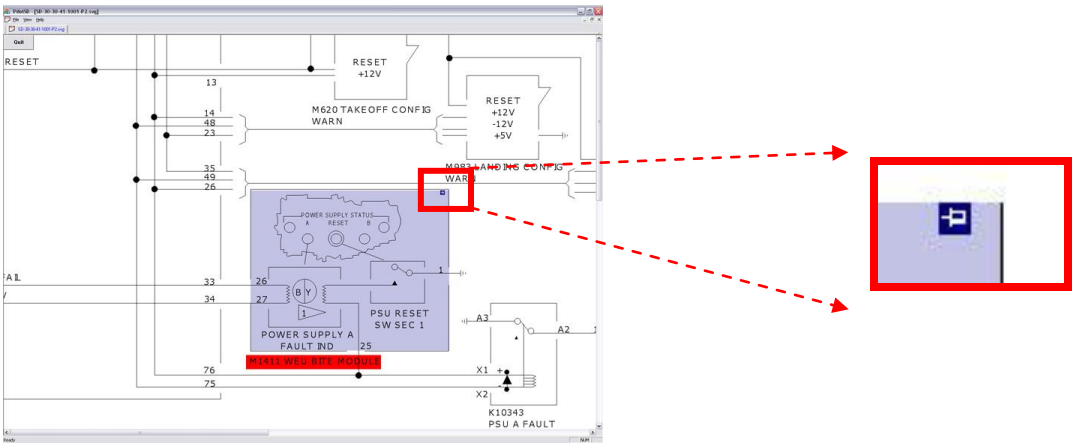


<View transformed by vertical scrolling (left) and panning (right) a diagram>

2) Highlight a component and a link

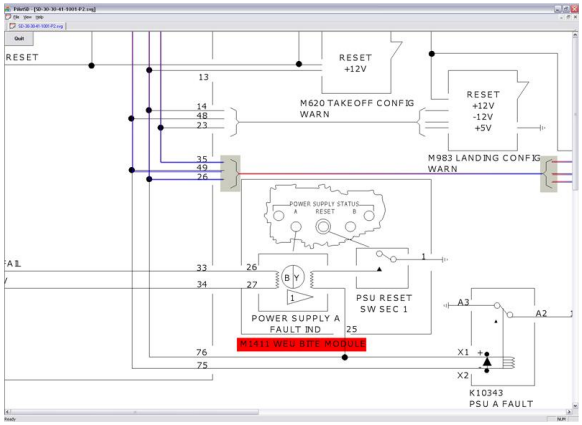
Place the mouse cursor on a component or a link in the diagram (you don't need to click any mouse buttons). The component is focused with a pin icon ( ) in its upper right corner and highlighted in light purple. The link is highlighted in color changing from red to blue making two end-components highlighted. This highlighting will be maintained while moving and holding the left mouse button.

1. Move the mouse cursor to the component "M1411 WEU BITE MODULE", and see the component highlighted.
2. Hold the left mouse button on the component "M1411 WEU BITE MODULE", and move the mouse.



<Highlight a component>

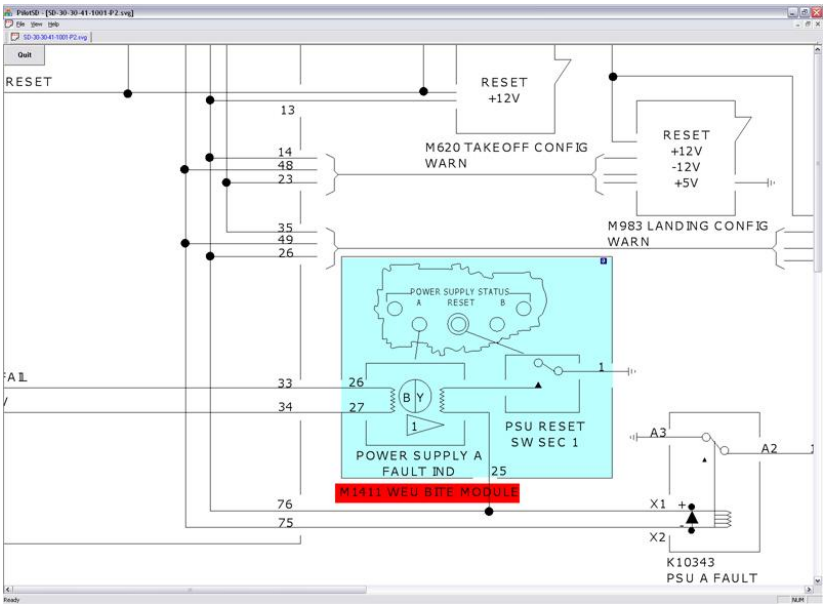
3. Move the mouse cursor to any link around "M1411 WEU BITE MODULE" like the figure below.
4. Hold the left mouse button on the link, and move the mouse.



<Highlight a link>

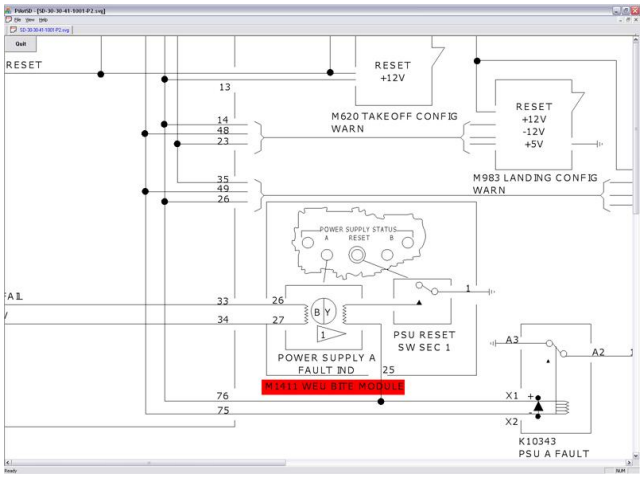
During the training and user test, you will also use the highlighting by double clicking to answer each subtask, and you should see the component highlighted in cyan. You can also double click a link but the highlighting color of a link will be the same.

1. Double click the “M1411 WEU BITE MODULE”, and confirm that the highlight color of the component is changed.



<Double click a component>

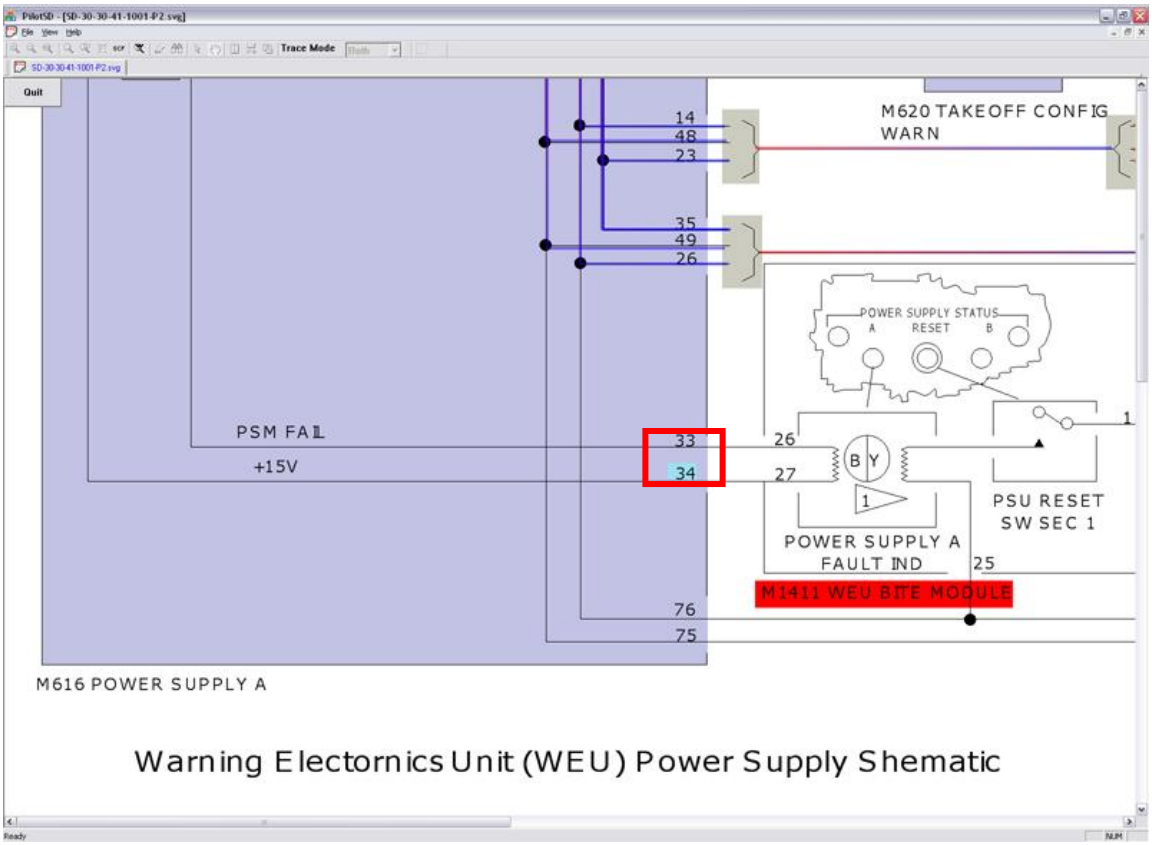
2. Double click the mouse button on any position of the background of the diagram to release it.



3) Find a pin number

Each component can have several pin numbers. You can double click on a pin number to select it, then the pin number will be highlighted in cyan.

1. Find the pin number on the “M616 POWER SUPPLY A” which connects to the pin 27 of the “M1411 WEU BITE MODULE”, and double click on the pin number.



4) Use rectangular fisheye lens based on mouse movement

A rectangular fisheye is a variation of a general circular fisheye lens that divides the screen into several small areas and applies different scale factors to each part. A fisheye lens distorts the view to enable seeing more contextual information (adjacent areas) while preserving the viewing of the focus area. In SDViz, the screen is divided into nine areas. The focus area around a mouse cursor has 1×1 scaling, whereas other areas are scaled down. You can move the fisheye lens on a diagram by moving a mouse without clicking.

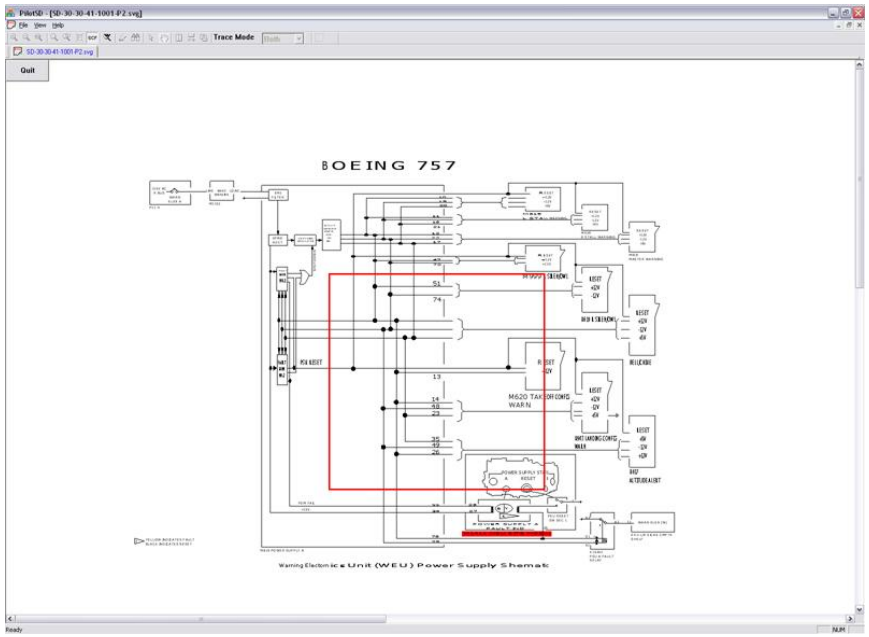
1. Select the icon, (

, Rectangular Fisheye Lens), on a toolbar menu.

   We assume that the diagram is very large so that you cannot read texts without a fisheye lens.
2. Move the mouse without clicking to see the distorted diagram.
3. Move the mouse fast or very slow.

   In this training, you can drag a diagram by holding down the left mouse button.
4. Hold down the left mouse button and move a diagram.
5. Find the pin number on the “M616 POWER SUPPLY A” which connects to “M620 TAKEOFF CONFIG WARN”, and double click on the pin number.
6. To turn off this lens, click the icon, (

), on a toolbar menu.

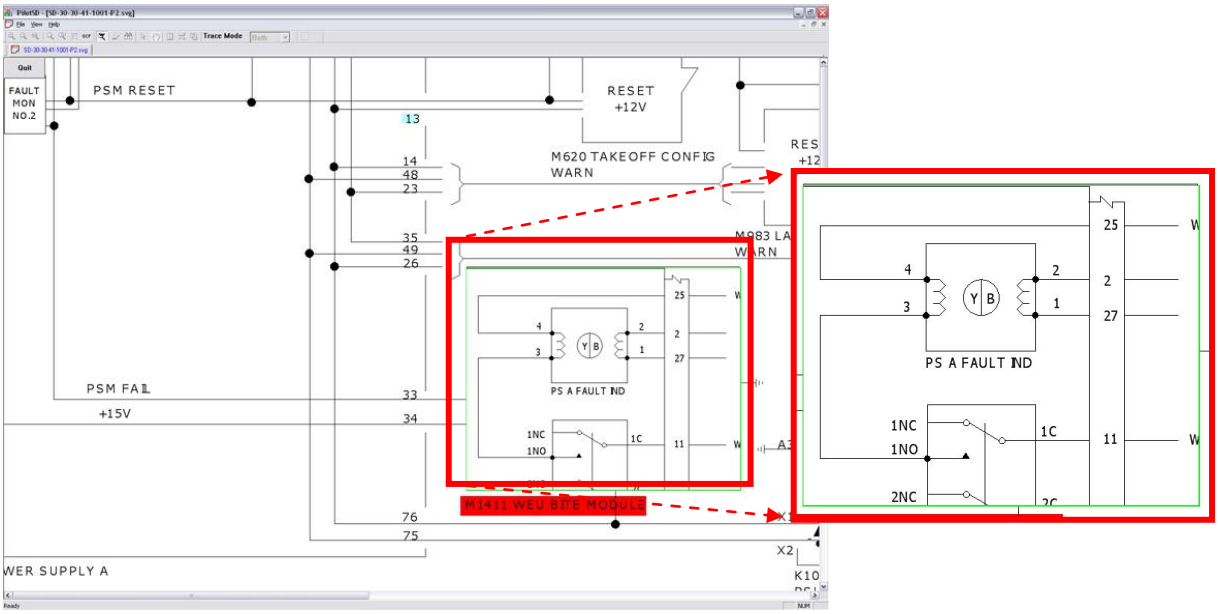


<A distorted diagram by rectangular fisheye lens>

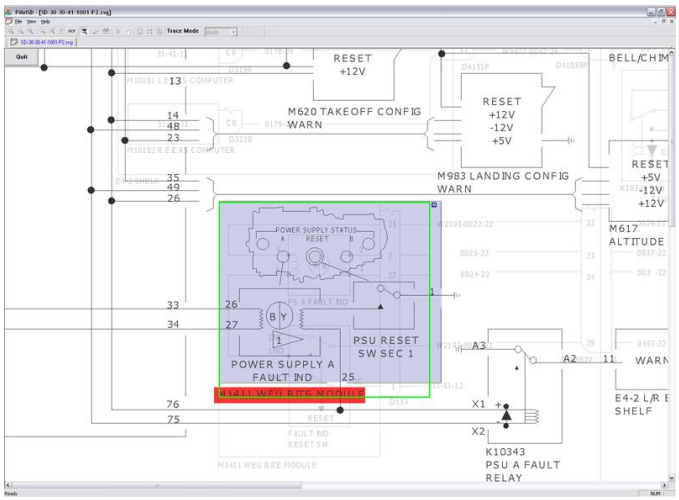
5) Use transition-by-blending

Transition-by-blending is a method to view the related diagram within the current diagram view without explicitly opening the related diagram preserving the spatial information (e.g., position on a screen) of the focused component between the two diagrams. You can use an up-arrow key to move the related diagram from the current.

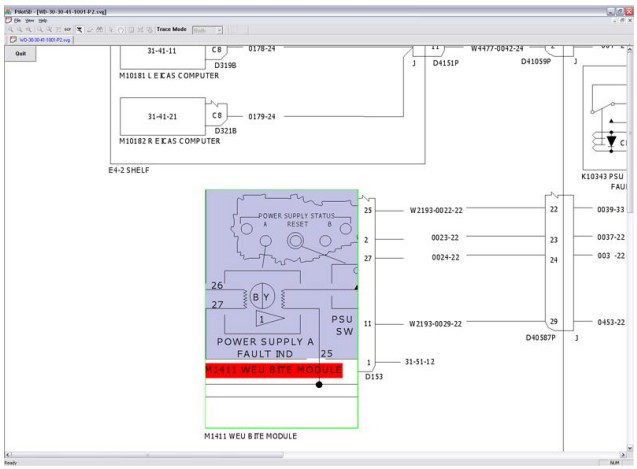
1. Select the icon, (, transition-by-blending) on the toolbar menu.
2. Mouse over a component, “M1411 WEU BITE MOUDLE.”



3. Press an up-arrow key. You will see diagrams blended.



4. Press the up-arrow key (four times) until you cannot see the blending effect.



5. When a view has moved completely to the related diagram, double click the component over which the mouse cursor is positioned. (The color will not be changed this time.)
6. The component you double clicked is the same as the component (“M1411 WEU BITE MOUDLE”).

You can also return to the initial diagram.

1. Place the mouse cursor on the component (“M1411 WEU BITE MOUDLE”).
2. Press the up-arrow key (five times) until you cannot see the blending effect.
3. Your mouse cursor should be over the same component (“M1411 WEU BITE MOUDLE”).
4. To turn off this lens, click the icon, ( ), on the toolbar menu again.

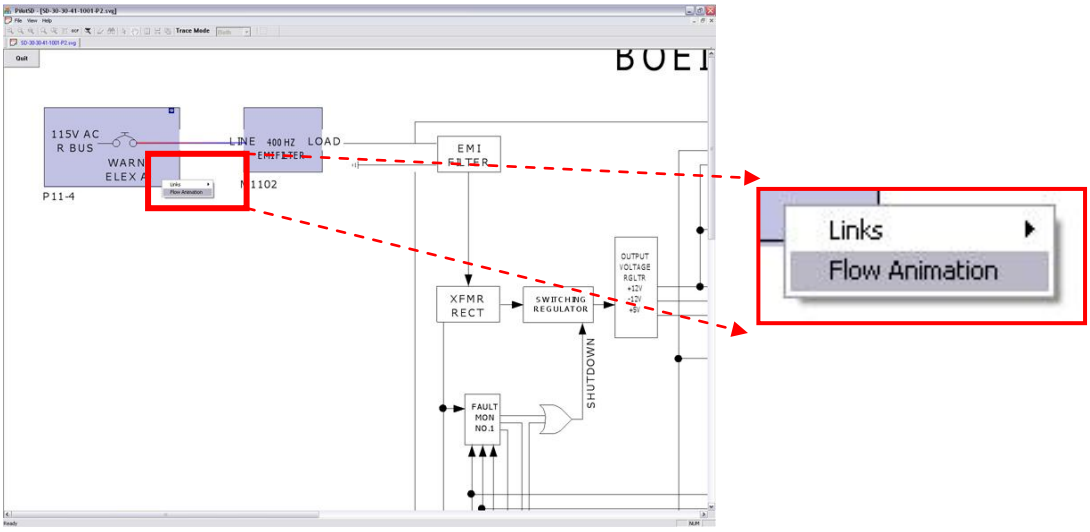
You can use this function to find the same component in the related diagram.

6) Use Flow animation

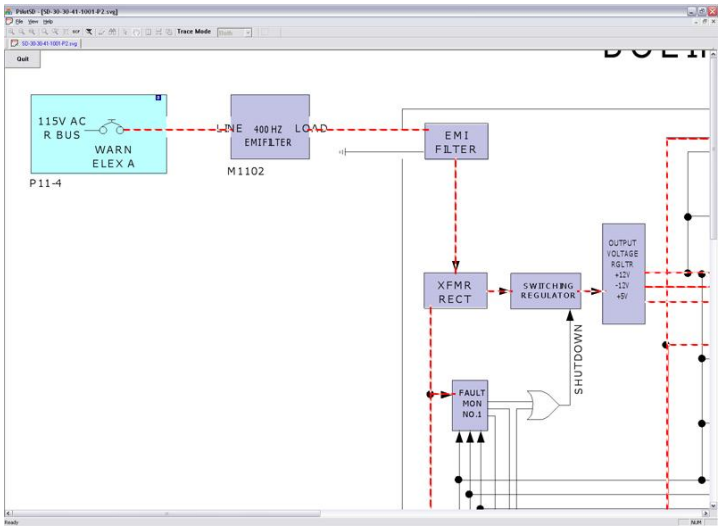
In SDViz, flow animation shows flow on the path between components. On any path animated, you can find the source (the first component) or sink (the last component).

In SD-30-41-1001-P2.svg,

1. Mouse over a component, “P11-4”.
2. Right click on the component, and select “Flow Animation”.
3. Find the component, “M615 L STALL WARNING”, on the path of links animated from the “P11-4” by following the animated flow.



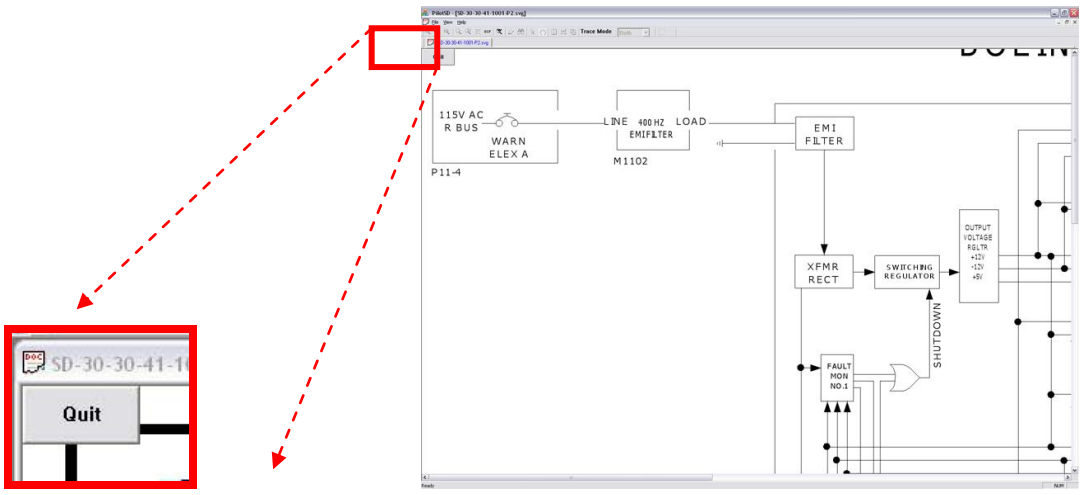
<Start Flow animation>



<Flow animated from the selected component>

7) Exit the training

1. To exit the training, select the “Quit” button on the left-top corner.



<Quit the training>

Evaluation Questions (Task 2 and Task 3 Training)

Once you feel you understand how to use the system, you will be given evaluation questions. You must receive 100 percent on the evaluation to continue to the experiment.

Instructions for Task 2 (Task 2A-1)

Subtask 1

For this subtask, you start with a wiring diagram containing a component ("**L9 L Side Window Power On Light**") highlighted in cyan. The diagram will be distorted by one lens that you have to use, and you cannot scroll or pan the diagram for this subtask.

When you double click a pin number to mark the answer, a message box stating "Is this your answer?" will appear. Click the "OK" button to record your answer, or click "Cancel."

If your answer is wrong, you will get the message ("You made a wrong answer. Please try it again.") and this subtask will not be finished. You have three chances to find the correct answer.

Step #	**Instruction**
1	• (Group A) You will use a rectangular fisheye lens based on the mouse movement. • (Group B) You will use a magic lens. • Double click the pin number on the "E3-3 Electrical Shelf" connecting to the initial highlighted component, "L9 L Side Window Power On Light".

Instructions for Task 2 (Task 2A-2)

Subtask 2

For this subtask, you start with a wiring diagram containing a component ("**L13 Right Front Window Power On LT**") highlighted in cyan. The diagram will be distorted by one lens that you have to use, and you cannot scroll or pan the diagram for this subtask.

When you double click a pin number to mark the answer, a message box stating "Is this your answer?" will appear. Click the "OK" button to record your answer, or click "Cancel."

If your answer is wrong, you will get the message ("You made a wrong answer. Please try it again.") and this subtask will not be finished. You have three chances to find the correct answer.

Step #	**Instruction**
1	• (Group A) You will use a rectangular fisheye lens based on the mouse movement. • (Group B) You will use a magic lens. • Double click the pin number on the "E3-3 Electrical Shelf" connecting to the initial highlighted component, "L13 Right Front Window Power On LT".

Instructions for Task 2 (Task 2A-3)

Subtask 3

For this subtask, you start with a wiring diagram containing a component ("**L10 L. Side Window O/H LT**") highlighted in cyan. The diagram will be distorted by one lens that you have to use, and you cannot scroll or pan the diagram for this subtask.

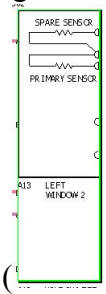
When you double click a pin number to mark the answer, a message box stating "Is this your answer?" will appear. Click the "OK" button to record your answer, or click "Cancel."

If your answer is wrong, you will get the message ("You made a wrong answer. Please try it again.") and this subtask will not be finished. You have three chances to find the correct answer.

Step #	**Instruction**
1	• (Group A) You will use a rectangular fisheye lens based on the mouse movement. • (Group B) You will use a magic lens. • Double click the pin number on the "E3-3 Electrical Shelf" connecting to the initial highlighted component, "L10 L. Side Window O/H LT".

Instructions for Task 2 (Task 2B-1)

Subtask 1

(Group A) For this subtask, you start with a schematic diagram containing a component ("**A13 Window Left Side 2**") highlighted with a green rectangle. (

).

(Group B) For this subtask, you start with a schematic diagram containing a component ("**A13 Window Left Side 2**") highlighted in cyan.

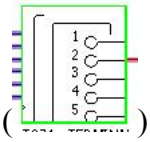
When you double click a component to mark the answer, a message box stating "Is this your answer?" will appear. Click the "OK" button to record your answer, or click "Cancel."

If your answer is wrong, you will get the message ("You made a wrong answer. Please try it again.") and this subtask will not be finished. You have three chances to find the correct answer.

Step #	**Instruction**
1	• (Group A) Use the function "transition-by-blending". • (Group B) Use the tabbed window. • Find the same component to the initial component highlighted in a related wiring diagram. (Not in the current diagram.) • Double click on the component.

Instructions for Task 2 (Task 2B-2)

Subtask 2

(Group A) For this subtask, you start with a schematic diagram containing a component ("**T271 Terminal Strip**") highlighted with a green boundary rectangle ().

(Group B) For this subtask, you start with a schematic diagram containing a component ("**T271 Terminal Strip**") highlighted in cyan.

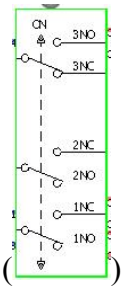
When you double click a component to mark the answer, a message box stating "Is this your answer?" will appear. Click the "OK" button to record your answer, or click "Cancel."

If your answer is wrong, you will get the message ("You made a wrong answer. Please try it again.") and this subtask will not be finished. You have three chances to find the correct answer.

Step #	**Instruction**
1	• (Group A) Use the function "transition-by-blending". • (Group B) Use the tabbed window. • Find the same component to the initial component highlighted in a related wiring diagram. (Not in the current diagram.) • Double click on the component.

Instructions for Task 2 (Task 2B-3)

Subtask 3

(Group A) For this subtask, you start with a schematic diagram containing a component ("**S3 L Side Window SW**") highlighted with a green boundary rectangle (

).

(Group B) For this subtask, you start with a schematic diagram containing a component ("**S3 L Side Window SW**") highlighted in cyan.

When you double click a component to mark the answer, a message box stating "Is this your answer?" will appear. Click the "OK" button to record your answer, or click "Cancel."

If your answer is wrong, you will get the message ("You made a wrong answer. Please try it again.") and this subtask will not be finished. You have three chances to find the correct answer.

Step #	**Instruction**
1	• (Group A) Use the function "transition-by-blending". • (Group B) Use the tabbed window. • Find the same component to the initial component highlighted in a related wiring diagram. (Not in the current diagram.) • Double click on the component.

Instructions for Task 3 (Task 3-1)

Subtask 1

For this subtask, you start with a schematic diagram containing highlighted links and the component ("Refueling Valve Cont").

When you double click a component to mark the answer, a message box stating "Is this your answer?" will appear. Click the "OK" button to record your answer, or click "Cancel."

If your answer is wrong, you will get the message ("You made a wrong answer. Please try it again.") and this subtask will not be finished. You have three chances to find the correct answer.

Step #	**Instruction**
1	• Find the source component of the path highlighted. • Double click the component.

Instructions for Task 3 (Task 3-2)

Subtask 2

For this subtask, you start with a schematic diagram containing highlighted links and the component ("Fueling Shutoff Valve").

When you double click a component to mark the answer, a message box stating "Is this your answer?" will appear. Click the "OK" button to record your answer, or click "Cancel."

If your answer is wrong, you will get the message ("You made a wrong answer. Please try it again.") and this subtask will not be finished. You have three chances to find the correct answer.

Step #	**Instruction**
1	• Find the source component of the path highlighted. • Double click the component.

Appendix C-3-b. Instruction sheet for Tasks 2 and 3 *(Group B)*

Evaluation Study: Novel Presentation Methods for Technical Data

Hello, and welcome to this evaluation study. Please refer to this document during your experiment, as it will provide you with all necessary instructions for completing your task. Whenever you are not sure about the task or if you do not feel comfortable at any time during the experiment, please TELL us.

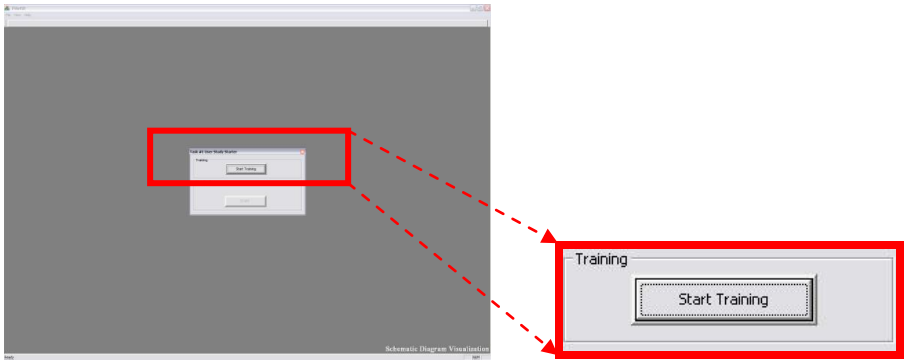
Your task

During this experiment you will be asked to find different components in various diagrams per the written instructions. The system will log the timing and mouse clicks and movement information. The goal is to find the component as quickly as possible while maintaining 100 percent accuracy.

How to use SDViz?

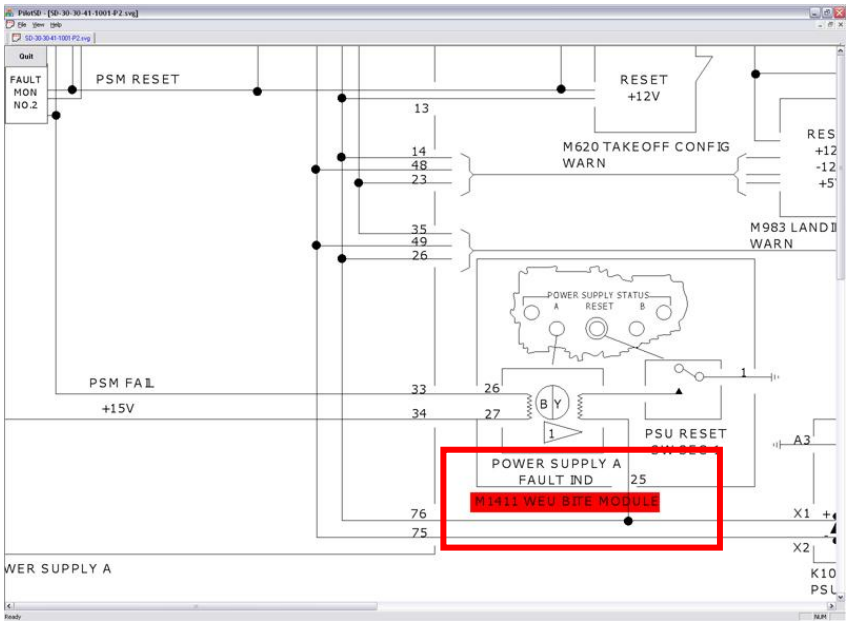
Before starting this evaluation study, you will be trained in the use of SDViz. Please read the instructions detailing the SDViz features and complete the training tasks. When you feel comfortable with the system you will be asked to take a short quiz. You must score 100 percent on this quiz in order to continue on to the experiment. You may take as long as you feel necessary for training.

<Training Instructions>
First, click the "Start Training" button in the initial dialog, User Study Starter.



<Initial Screenshot>

You will start our training using the schematic diagram containing the component (“M1411 WEU BITE MODULE”) highlighted in red.

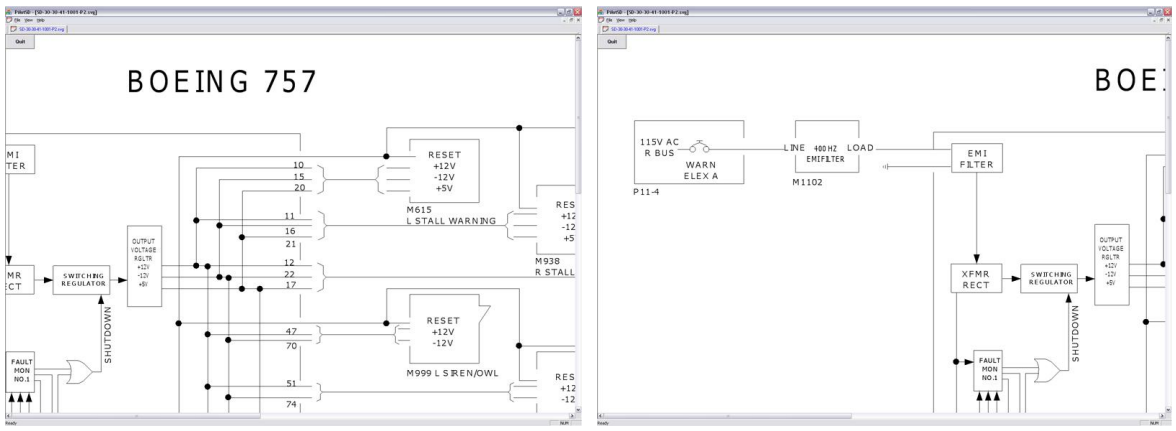


<Initial highlighting for training>

1) Scrolling / panning a diagram

You can scroll or pan a diagram to transform the view. To scroll a diagram, use the vertical/horizontal scroll bars on the right/bottom side of the SDViz. To pan a diagram, you can left click and hold the mouse button dragging a diagram.

1. Scroll or pan a diagram to make the view like figures below.

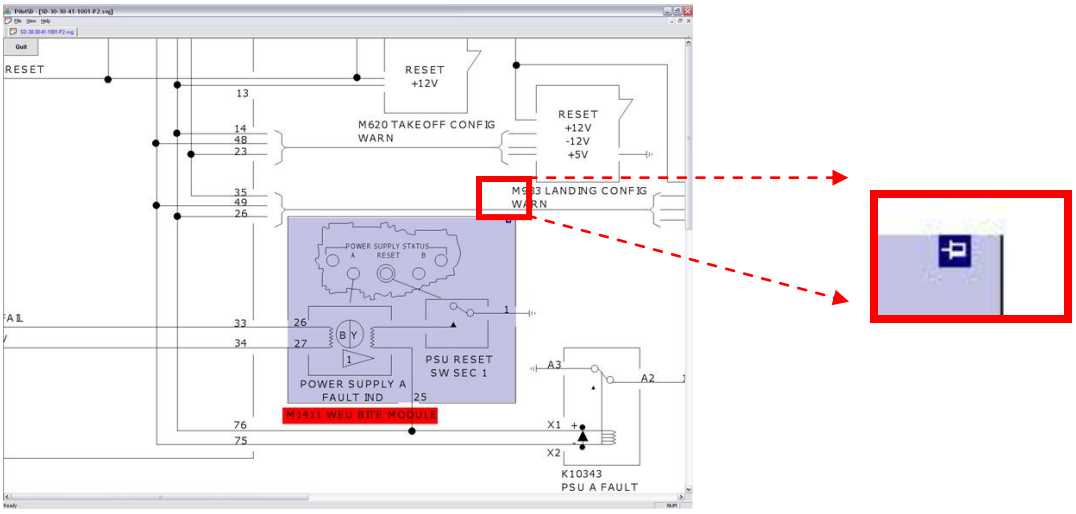


<View transform by vertical scrolling (left) and panning (right) a diagram>

2) Highlight a component and a link

Place the mouse cursor on a component or a link in the diagram (you don't need to click any mouse buttons). The component is focused with a pin icon ( ) in its upper right corner and highlighted in light purple. The link is highlighted in color changing from red to blue making two end-components highlighted. These highlightings will be maintained while moving and holding the left mouse button.

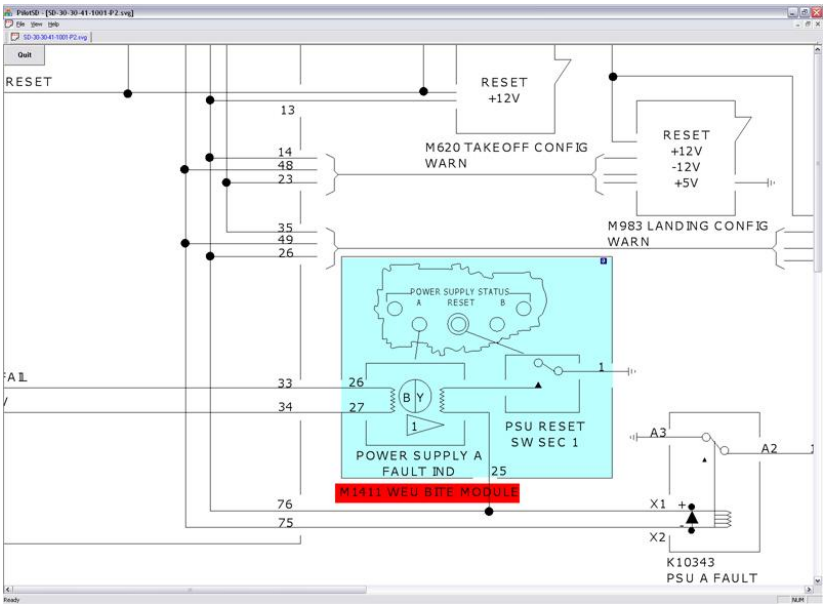
1. Move the mouse cursor to the component "M1411 WEU BITE MODULE", and see the component highlighted.
2. Hold the left mouse button on the component "M1411 WEU BITE MODULE", and move the mouse.



<Highlight a component>

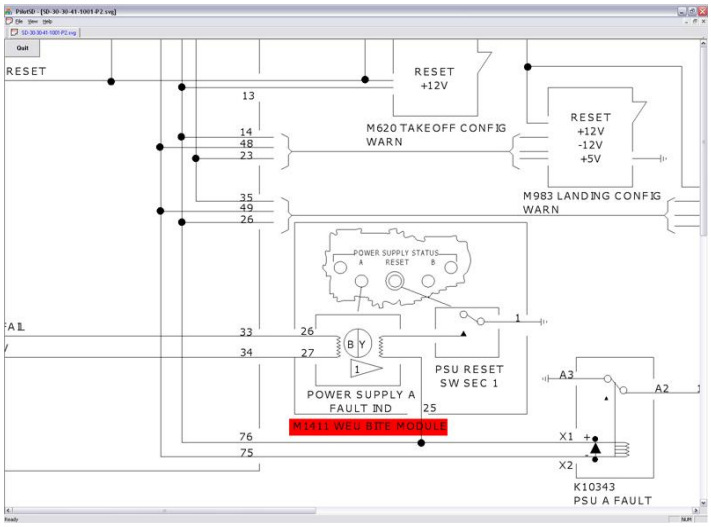
During the training and user test, you will also use the highlighting by double click to answer each subtask, and you should see the component highlighted in cyan. You can also double click a link but the highlighting color of a link will be the same.

1. Double click the "M1411 WEU BITE MODULE," and confirm that the highlight color of the component is changed.



<Double click a component>

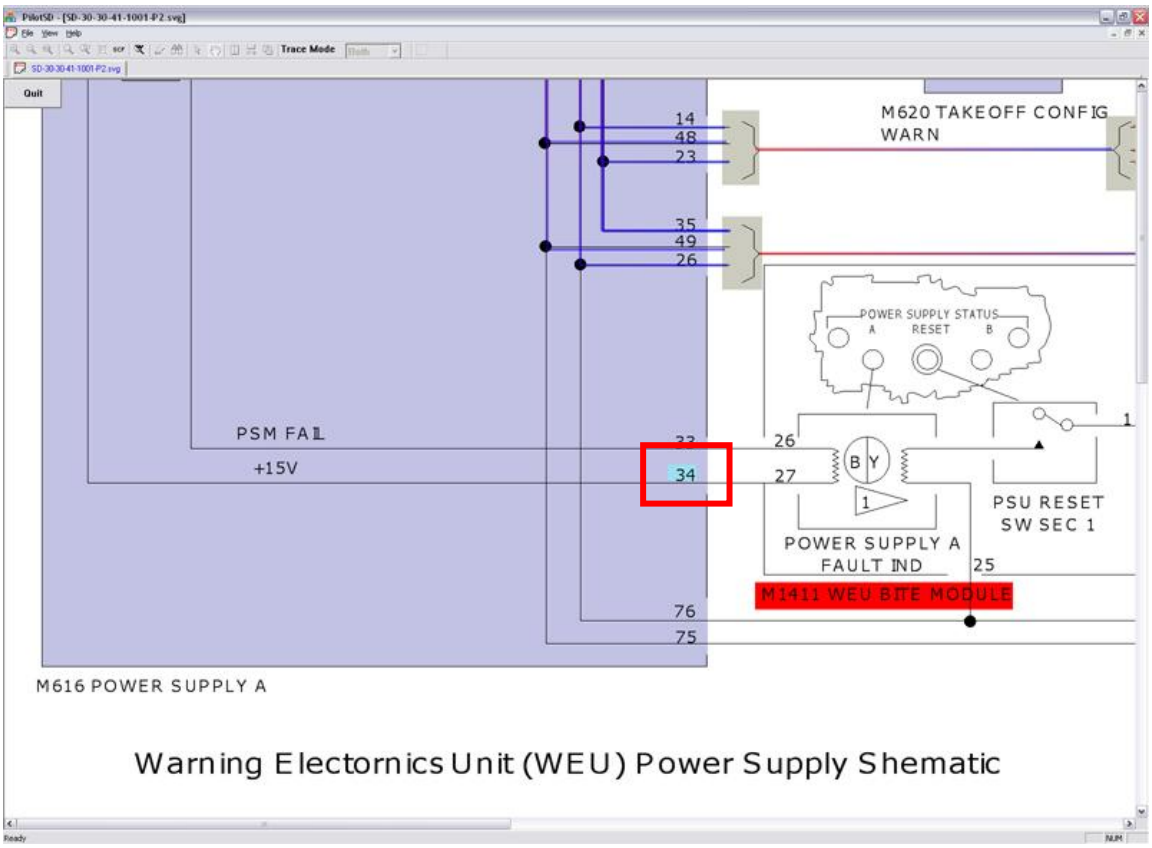
2. Double click the mouse button on any position of the background of the diagram to release it.



3) Find a pin number

Each component can have several pin numbers. You can double click on a pin number to select it, then the pin number will be highlighted in cyan.

1. Find the pin number on the “M616 POWER SUPPLY A” which connects to the pin 27 of the “M1411 WEU BITE MODULE,” and double click on the pin number.



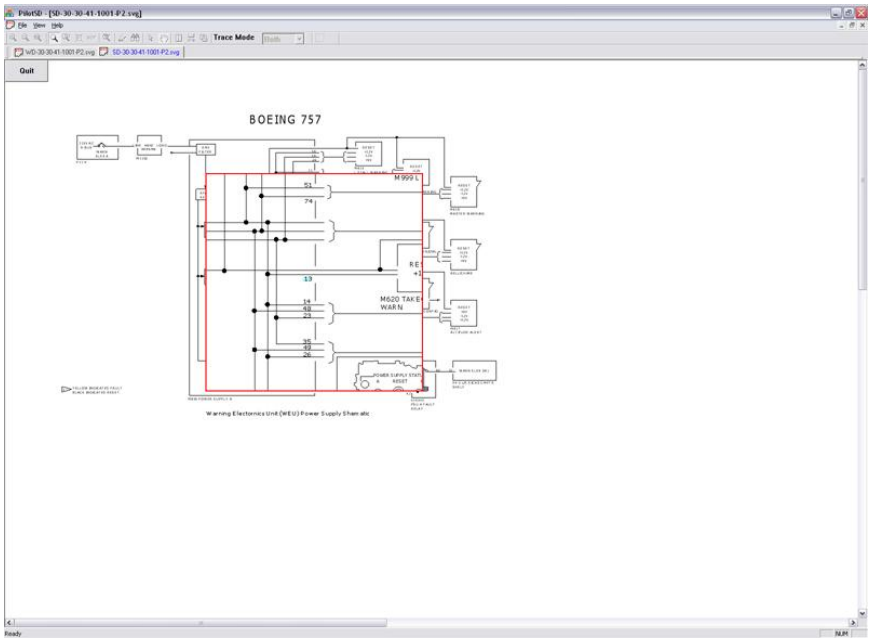
4) Use magic lens

A magic lens is similar to a magnifying glass and can be used to visualize and emphasize the details of a portion of a diagram. The diagram displayed under the fixed-size lens can be shown in much larger scale than the current diagram. In SDViz, the system magnifies the portion of a diagram under the lens, and you can move the magic lens on a diagram by moving a mouse without clicking.

1. Select the icon, (, Magic Lens), on a toolbar menu.

   We assume that diagram is very large so that you cannot read text without a magic lens.
2. Move a mouse without clicking to see the effect of a magic lens.

   In this training, you can drag a diagram by holding a left mouse button.
3. Hold the left mouse button and move a diagram.
4. Find the pin number on the “M616 POWER SUPPLY A” which connects to “M620 TAKEOFF CONFIG WARN,” and double click on the pin number.
5. To turn off this lens, click the icon, ( ), on a toolbar menu.



<A magnified diagram by a magic lens>

5) Use tabbed window viewing

SDViz provides traditional tabbed window viewing, which can be used to move between opened diagrams. When a diagram is open, a tab interface is also displayed on the top-left of the diagram with the file name as a title. If multiple diagrams are opened, a new tab will be displayed next to the previous one. You can select one of the tabs to change the current active diagram.

You have two diagrams opened. See the tab interfaces on the left top of a diagram.

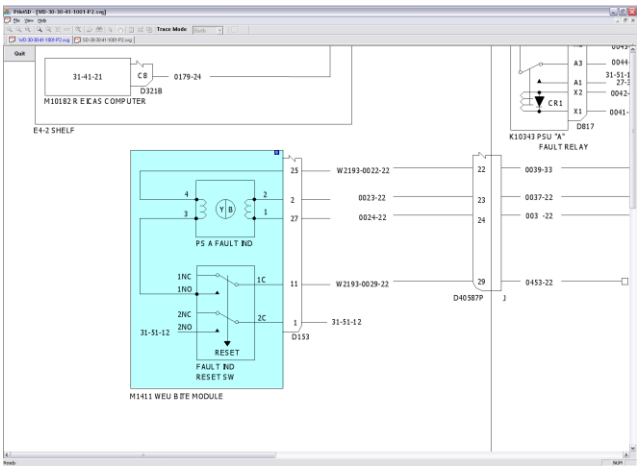
1. Select “WD-30-30-41-1001-P2.svg” tab.

   It is a wiring diagram related to previous schematic diagrams.

2. Return by selecting “SD-30-30-41-1001-P2.svg” tab.
3. Find the component, “M1411 WEU BITE MODULE.”

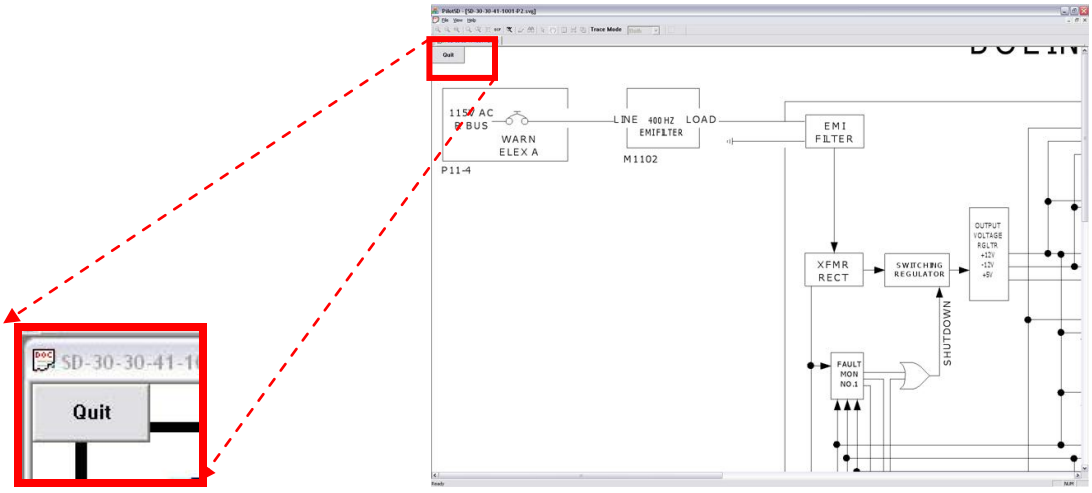
   Now, you will find the component, “M1411 WEU BITE MODULE,” in the wiring diagram, “WD-30-30-41-1001-P2.svg.”

4. Find the component, “M1411 WEU BITE MODULE,” in “WD-30-30-41-1001-P2.svg.”
5. Double click the component.



6) Exit the training

1. To exit the training, select the “Quit” button on the left top corner.



<Quit the training>

Evaluation Questions (Task 2 and Task 3 Training)

Once you feel you understand how to use the system, you will be given evaluation questions. You must receive 100 percent on the evaluation to continue to the experiment.

Appendix C-4-a. Post-task Questionnaire for Tasks 2 and 3 *(Group A)*

Evaluation Study: Novel Presentation Methods for Technical Data

The following questions will be used to collect information for our evaluation study. Please mark your response or write down the answer.

Q1. Mark one of the numbers to describe your overall impression of **how easy it is to use the user interface of SDViz**.

(1: Very easy, 2: Easy, 3: No opinion, 4: Not easy, 5: Difficult, or Not Applicable [N/A])

- Rectangular fisheye lens based on mouse movement [1 2 3 4 5 N/A]
- Transition-by-blending [1 2 3 4 5 N/A]
- Flow animation [1 2 3 4 5 N/A]

Comments:

(Please give your comments.)

Q2. Mark one of the numbers to describe your opinion of **which features are useful**.

(1: Very useful, 2: Useful, 3: No opinion, 4: Not bad, 5: Not useful, or Not Applicable [N/A])

- Rectangular fisheye lens based on mouse movement [1 2 3 4 5 N/A]
- Transition-by-blending [1 2 3 4 5 N/A]
- Spatial information maintained by transition-by-blending [1 2 3 4 5 N/A]
- Flow animation [1 2 3 4 5 N/A]

Comments:

(Please give your comments.)

Q3. You tested finding a specific pin number by using a rectangular fisheye lens based on mouse movement assuming the diagram on a screen is very large so that you cannot read the text clearly. Mark one of the following to describe your opinion of **how useful it was to use the function in finding the desired information.** Please, give the reason for your answer in below blank area.

Useful Not-useful

1 2 3 4 5

Comments:

(Please give your comments.)

Q4. You tested finding a specific component in the related diagram by using transition-by-blending. Mark one of the following to describe your opinion of **how easy it was to use the function in finding the desired information.** Please, give the reason for your answer in below blank area.

Easy Difficult

1 2 3 4 5

Comments:

(Please give your comments.)

Q5. You tested finding a specific component in a horizontally long diagram by using flow animation. Mark one of the following to describe your opinion of **how easy it was to use the function in finding the desired information.** Please, give the reason for your answer in below blank area.

Easy Difficult

1 2 3 4 5

Comments:

(Please give your comments.)

Thank you for your time.

Appendix C-4-b. Post-task Questionnaire for Tasks 2 and 3 *(Group B)*

Evaluation Study: Novel Presentation Methods for Technical Data

The following questions will be used to collect information for your evaluation study. Please mark your response or write down the answer.

Q1. Mark one of the numbers to describe your overall impression of **how easy it is to use the user interface of SDViz**.

(1: Very easy, 2: Easy, 3: No opinion, 4: Not easy, 5: Difficult, or Not Applicable [N/A])

- Magic lens [1 2 3 4 5 N/A]
- Tabbed window interface [1 2 3 4 5 N/A]

Comments:

(Please give your comments.)

Q2. Mark one of the numbers to describe your opinion of **which features are useful**.

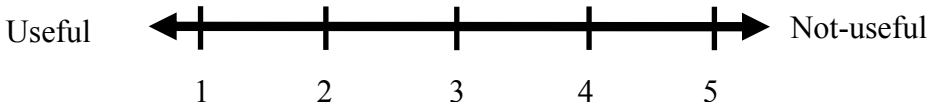
(1: Very useful, 2: Useful, 3: No opinion, 4: Not bad, 5: Not useful, or Not Applicable [N/A])

- Magic lens [1 2 3 4 5 N/A]
- Move to another diagram by using a tab interface [1 2 3 4 5 N/A]

Comments:

(Please give your comments.)

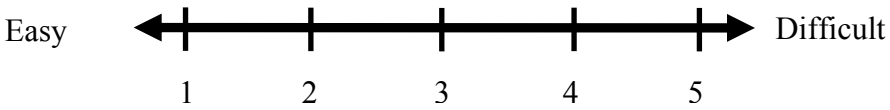
Q3. You tested finding a specific pin number by using magic lens assuming the diagram on a screen is very large so that you cannot read the text clearly. Mark one of the following to describe your opinion of **how useful it was to use the function in finding the desired information.** Please, give the reason for your answer in below blank area.



Comments:

(Please give your comments.)

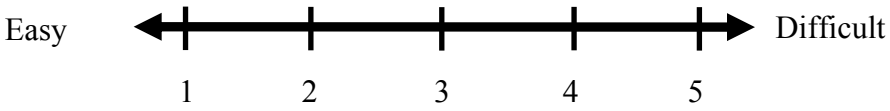
Q4. You tested finding a specific component in the related diagram by using tabbed window viewing. Mark one of the following to describe your opinion of **how easy it was to use the function in finding the desired information.** Please, give the reason for your answer in below blank area.



Comments:

(Please give your comments.)

Q5. You tested finding a specific component in a horizontally long diagram by highlighting links. Mark one of the following to describe your opinion of **how easy it was to use the function in finding the desired information.** Please, give the reason for your answer in below blank area.



Comments:

(Please give your comments.)

Thank you for your time.

Appendix D-1. Classification for User Study of Task 1B, Task 2, and Task 3

We perform the revised Task 1B together with the user study for Task 2 and Task 3. Therefore, we make groups of subjects as follows.

---

1. Tasks

- Task 1B (Task 1B-1, Task 1B-2, Task 1B-3)
  - Group A: Highlighting
  - Group B: Highlighting + Spatial information
  - Group C: (nothing)
  - Group D: Spatial information
- Task 2A (Task 2A-1, Task 2A -2, Task 2A -3)
  - Group A: Rectangular fisheye based on the mouse movement
  - Group B: Magic lens
- Task 2B (Task 2B-1, Task 2B-2, Task 2B-3)
  - Group A: Transition-by-blending
  - Group B: Traditional tabbed window viewing
- Task 3 (Task 3-1, Task 3 -2)
  - Group A: Flow animation
  - Group B: Static connection highlighted (but, not maintained)

2. Grouping for user study

cf. Task 1B and Task 2 use the same diagrams (schematic and wiring). Moreover, the subtasks for Task 1B and Task 2A are exactly the same. So, they cannot be performed by the same subject.

- Task 1B & Task 3: (total 5 subtasks)
  - Group A: performs Task 1B Group A and Task 3 Group A
  - Group B: performs Task 1B Group B and Task 3 Group A
  - Group C: performs Task 1B Group C and Task 3 Group B
  - Group D: performs Task 1B Group D and Task 3 Group B
- Task 2 & Task 3: (total 8 subtasks)
  - Group A: performs Task 2A Group A, Task 2B Group A, and Task 3 Group A
  - Group B: performs Task 2A Group B, Task 2B Group B, and Task 3 Group B

3. Subtask order

- Task 1B & Task 3: (total 5 subtasks)
  - Subtask 1 : Task 1B-2
  - Subtask 2 : Task 3-2
  - Subtask 3 : Task 3-1
  - Subtask 4 : Task 1B-1
  - Subtask 5 : Task 1B-3
- Task 2 & Task 3: (total 8 subtasks)
  - Subtask 1 : Task 2A-2
  - Subtask 2 : Task 3-1
  - Subtask 3 : Task 2B-3
  - Subtask 4 : Task 3-2
  - Subtask 5 : Task 2B-2
  - Subtask 6 : Task 2A-1
  - Subtask 7 : Task 2B-1
  - Subtask 8 : Task 2A-3

APPENDIX B

XML Data DTDs (Document Type Definitions)

B.1 Systeminfo.xdb

```
<!ELEMENT systeminfo (vehicles, systems) />
<!ELEMENT vehicles (vehicle)* />
<!ELEMENT vehicle EMPTY />
<!ATTLIST vehicle
        id ID # REQUIRED
        name CDATA # REQUIRED />
<!ELEMENT systems (system)* />
<!ELEMENT system EMPTY />
<!ATTLIST system
        id ID # REQUIRED
        name CDATA # REQUIRED />
```

B.2 TO.xdb

The document elements listed below are used in SDViz and are parts of MIL-PRF-87269a.

```
<!ELEMENT techinfo (version, system) />
<!ATTLIST techinfo
        name    CDATA #REQUIRED/>
<!ELEMENT version EMPTY/>
<!ATTLIST version
        revision CDATA #REQUIRED/>
<!ELEMENT system (system?, descinfo) />
<!ATTLIST system
        id    ID   #REQUIRED
        name CDATA #REQUIRED/>
<!ELEMENT descinfo (para-seq)* />
<!ELEMENT para-seq (para)* />
<!ELEMENT para (sub-prims)* />
<!ELEMENT sub-prims graphic />
<!ELEMENT graphic link />
<!ATTLIST graphic
        name CDATA
```

```
            type (schematic | wiring) #IMPLIED/>
<!ELEMENT link EMPTY />
<!ATTLIST link
        linkends CDATA #REQUIRED/>
```

B.3 XML

```
<!ELEMENT schematic (components, connectorGroups, links, connectors, routes)/>
<!ELEMENT components (component)*/>
<!ELEMENT component EMPTY/>
<!ATTLIST component
            id ID     #REQUIRED
            x CDATA #REQUIRED
            y CDATA #REQUIRED
            width CDATA #REQUIRED
            height CDATA #REQUIRED/>
<!ELEMENT connectorGroups (connectorGroup)*/>
<!ELEMENT connectorGroup EMPTY />
<!ATTLIST connectorGroup/>
<!ELEMENT connectors (connector)* />
<!ELEMENT connector (point)* />
<!ATTLIST connector
            id CDATA #REQUIRED/>
<!ELEMENT point EMPTY />
<!ATTLIST point
            x CDATA #REQUIRED
            y CDATA #REQUIRED/>
<!ELEMENT routes (route)* />
<!ELEMENT route EMPTY />
<!ATTLIST route
            id    IDREF #REQUIRED
            srcid IDREF #REQUIRED
            dstid IDREF #REQUIRED/>
```

APPENDIX C

Feedback by Post-Questionnaires

(Unit: percentage [%])

<Answers from subjects in Task 1 Group A>

Q1. Mark one of the numbers to describe your overall impression of **how easy it is to use the user interfaces of SDViz**.

	1	2	3	4	5	NA
• Highlighting a component.	80	20				
• Moving to the related wiring diagram.	60	30				10
• Using the tab interface	80	10				10
• Highlighting the path to the power source.	60	20	10			10

Q2. Mark one of the numbers to describe your overall impression of **how easy it is to use the user interfaces of SDViz**.

	1	2	3	4	5	NA
• Highlight components	80	20				
• Highlight links (connections)	80	10	10			
• Move to the related diagram by using Link menu	90	10				
• Move to another diagram by using a tab interface	90	10				
• Find the power source by highlighting the path	60	40				
• Maintain the context information between related diagrams	70	30				

Q3. You tested finding a specific component (power source) by highlighting the path to the power source. Choose one of the following to describe your opinion of **how useful it was to use the function in finding the power source.**

	1	2	3	4	5
Useful ←→ Not-useful	70	30			

Q4. Choose one of the following to describe your overall impression of **how easy it was to find the desired information in related diagrams by maintaining the context between related diagrams when you moved to the related diagrams**.

	1	2	3	4	5
Easy ←→ Difficult	70	30	0	0	0

<Answers from subjects in Task 1 Group B>

Q1. Mark one of the numbers to describe your overall impression of **how easy it is to use the user interfaces of SDViz**.						
	1	2	3	4	5	NA
• Highlighting a component.	67	11	11	0	11	0
• Moving to the related wiring diagram.	78	11	0	0	11	0
• Using the tab interface	67	22	0	0	11	0

Q2. Mark one of the numbers to describe your overall impression of **how easy it is to use the user interfaces of SDViz**.						
	1	2	3	4	5	NA
• Highlight components	22	22	45	0	11	0
• Move to the related diagram	56	22	11	0	11	0
• Using a tab interface	56	22	0	0	11	11

Q3. Choose one of the following to describe your overall impression of **how easy it was to find the power source from any component**.						
			1	2	3	4	5
Useful	←→	Not-useful	0	22	56	22	0

Q4. Choose one of the following to describe your overall impression of **how easy it was to find desired information in related diagrams when you moved to the related diagrams**.						
			1	2	3	4	5
Easy	←→	Difficult	11	22	45	11	11

<Answers from subjects in new Task 1B Group A, Task 3 Group A>

Q1. Mark one of the numbers to describe your overall impression of **how easy it is to use the user interface of SDViz**.

	1	2	3	4	5	NA
• Highlighting a component.	80	20				
• Moving to the related wiring diagram.	80			20		
• Flow animation	60	20		20		

Q2. Mark one of the numbers to describe your opinion of **which features are useful**.

	1	2	3	4	5	NA
• Highlight components	80	20	0	0	0	0
• Highlight links (connections)	80	20	0	0	0	0
• Move to the related diagram by using link menu	100	0	0	0	0	0
• Maintain the context information between related diagram	100	0	0	0	0	0
• Flow animation	80	0	20	0	0	0

Q3. Choose one of the following to describe your overall impression of **how easy it was to find the desired information in related diagrams by using maintained contextual information between related diagrams when you moved to the related diagrams**.

	1	2	3	4	5
Easy ←→ Difficult	80	20			

Q4. You tested finding a specific component in a horizontally long diagram by using flow animation. Choose one of the following to describe your opinion of **how useful it was to use the function in finding the desired information**. Please, give the reason for your answer in below blank area.

	1	2	3	4	5
Easy ←→ Difficult	80	20			

<Answers from subjects in new Task 1B Group B, Task 3 Group A>

Q1. Mark one of the numbers to describe your overall impression of **how easy it is to use the user interface of SDViz**.

	1	2	3	4	5	NA
• Highlighting a component.	80	20				
• Moving to the related wiring diagram.	40	40	20			
• Flow animation	20	80				

Q2. Mark one of the numbers to describe your opinion of **which features are useful**.

	1	2	3	4	5	NA
• Highlight components	60	20	0	0	0	0
• Highlight links (connections)	80	20	0	0	0	0
• Move to the related diagram by using link menu	60	40	0	0	0	0
• Maintain the context information between related diagram	60	40	0	0	0	0

Q3. Choose one of the following to describe your overall impression of **how easy it was to find the desired information in related diagrams by using maintained contextual information between related diagrams when you moved to the related diagrams**.

	1	2	3	4	5
Easy ←→ Difficult	60	40			

Q4. You tested finding a specific component in a horizontally long diagram by highlighting links. Choose one of the following to describe your opinion of **how useful it was to use the function in finding the desired information.** Please, give the reason for your answer in below blank area.

	1	2	3	4	5
Easy ←→ Difficult	60	20		20	

<Answers from subjects in new Task 1B Group C, Task 3 Group B>

Q1. Mark one of the numbers to describe your overall impression of **how easy it is to use the user interfaces of SDViz**.

	1	2	3	4	5	NA
• Highlighting a component.	60	20		20		
• Moving to the related wiring diagram.	80					20

Q2. Mark one of the numbers to describe your opinion of **which features are useful**.

	1	2	3	4	5	NA
• Highlight components		20	20	60		
• Move to the related diagram by using link menu	40	40	20			

Q3. Choose one of the following to describe your overall impression of **how easy it was to find the desired information in related diagrams when you moved to the related diagrams**.

	1	2	3	4	5
Easy ←→ Difficult	20	60	20	0	0

Q4. You tested finding a specific component in a horizontally long diagram by highlighting links. Choose one of the following to describe your opinion of **how useful it was to use the function in finding the desired information.** Please, give the reason for your answer in below blank area.

	1	2	3	4	5
Easy ←→ Difficult	20	40	20	20	0

<Answers from subjects in new Task 1B Group D, Task 3 Group B>

Q1. Mark one of the numbers to describe your overall impression of **how easy it is to use the user interfaces of SDViz**.

	1	2	3	4	5	NA
• Highlighting a component.	80	20	0	0	0	0
• Moving to the related wiring diagram.	80	20	0	0	0	0

Q2. Mark one of the numbers to describe your opinion of **which features are useful**.

	1	2	3	4	5	NA
• Highlight components	60	40	0	0	0	0
• Move to the related diagram by using link menu	100	0	0	0	0	0
• Maintain the context information between related diagram	80	0	20	0	0	0

Q3. Choose one of the following to describe your overall impression of **how easy it was to find the desired information in related diagrams by using maintained contextual information between related diagrams when you moved to the related diagrams**.

	1	2	3	4	5
Easy ←→ Difficult	40	40	0	20	0

Q4. You tested finding a specific component in a horizontally long diagram by highlighting links. Choose one of the following to describe your opinion of **how useful it was to use the function in finding the desired information.** Please, give the reason for your answer in below blank area.

	1	2	3	4	5
Easy ←→ Difficult	60		40		

<Answers from subjects in Task 2 Group A, Task 3 Group A>

Q1. Mark one of the numbers to describe your overall impression of **how easy it is to use the user interface of SDViz**.

	1	2	3	4	5	NA
• Rectangular fisheye lens based on mouse movement		60	20	20		
• Transition-by-blending	60		20	20		
• Flow animation	80		20			

Q2. Mark one of the numbers to describe your opinion of **which features are useful**.

	1	2	3	4	5	NA
• Rectangular fisheye lens based on mouse movement	40	40		20		
• Transition-by-blending	80	20				
• Spatial information maintained by transition-by-blending	40	40		20		
• Flow animation	80	20				
• Flow animation						

Q3. You tested finding a specific pin number by using rectangular fisheye lens based on mouse movement assuming the diagram on a screen is very large so that you cannot read the text clearly. Choose one of the following to describe your opinion of **how useful it was to use the function in finding the desired information.** Please, give the reason for your answer in below blank area.

	1	2	3	4	5
Useful ←→ Not-useful	20	40	40		

Q4. You tested finding a specific component in the related diagram by using transition-by-blending. Choose one of the following to describe your opinion of **how useful it was to use the function in finding the desired information.** Please, give the reason for your answer in below blank area.

	1	2	3	4	5
Easy ←→ Difficult	40	40		20	

Q5. You tested finding a specific component in a horizontally long diagram by using flow animation. Choose one of the following to describe your opinion of **how useful it was to use the function in finding the desired information.** Please, give the reason for your answer in below blank area.

	1	2	3	4	5
Easy ←→ Difficult	80	20			

<Answers from subjects in Task 2 Group B, Task 3 Group B>

Q1. Mark one of the numbers to describe your overall impression of **how easy it is to use the user interfaces of SDViz**.

	1	2	3	4	5	NA
• Magic lens		20		40	40	
• Tabbed window interface	40	60				
• Flow animation		20	40	40		

Q2. Mark one of the numbers to describe your opinion of **which features are useful**.

	1	2	3	4	5	NA
• Magic lens		20	20	20	10	
• Highlighting links (connections)	40	40	20			
• Move to another diagram by using a tab interface	20	80				

Q3. You tested finding a specific pin number by using magic lens assuming the diagram on a screen is very large so that you cannot read the text clearly. Choose one of the following to describe your opinion of **how useful it was to use the function in finding the desired information.** Please, give the reason for your answer in below blank area.

	1	2	3	4	5
Useful ←→ Not-useful		20		40	40

Q4. You tested finding a specific component in the related diagram by using tabbed window viewing. Choose one of the following to describe your opinion of **how useful it was to use the function in finding the desired information.** Please, give the reason for your answer in below blank area.

	1	2	3	4	5
Easy ←→ Difficult	20	60	20		

Q5. You tested finding a specific component in a horizontally long diagram by highlighting links. Choose one of the following to describe your opinion of **how useful it was to use the function in finding the desired information.** Please, give the reason for your answer in below blank area.

	1	2	3	4	5
Easy ←→ Difficult	40	60			

ACRONYMS

ANOVA	Analysis Of Variance
AOI	Area Of Interest
GDI+	Extended Graphics Device Interface
SDViz	Schematic Diagram Visualization Tool
XML	Extensible Markup Language

GLOSSARY OF COLORS

Blue

Cyan

Green

Light Purple

Red